AD-A043 558 CONSTRUCTION ENGINEERING RESEARCH LAB (ARMY) CHAMPAI--ETC F/G 11/2
EVALUATION OF THE CORROSION RESISTANCE OF ALTERNATE REVETMENT W--ETC(U)
JUL 77 E P COX, C G CHEN

UNCLASSIFIED CERL-TR-M-221 NL

| OF |

AD
A043558

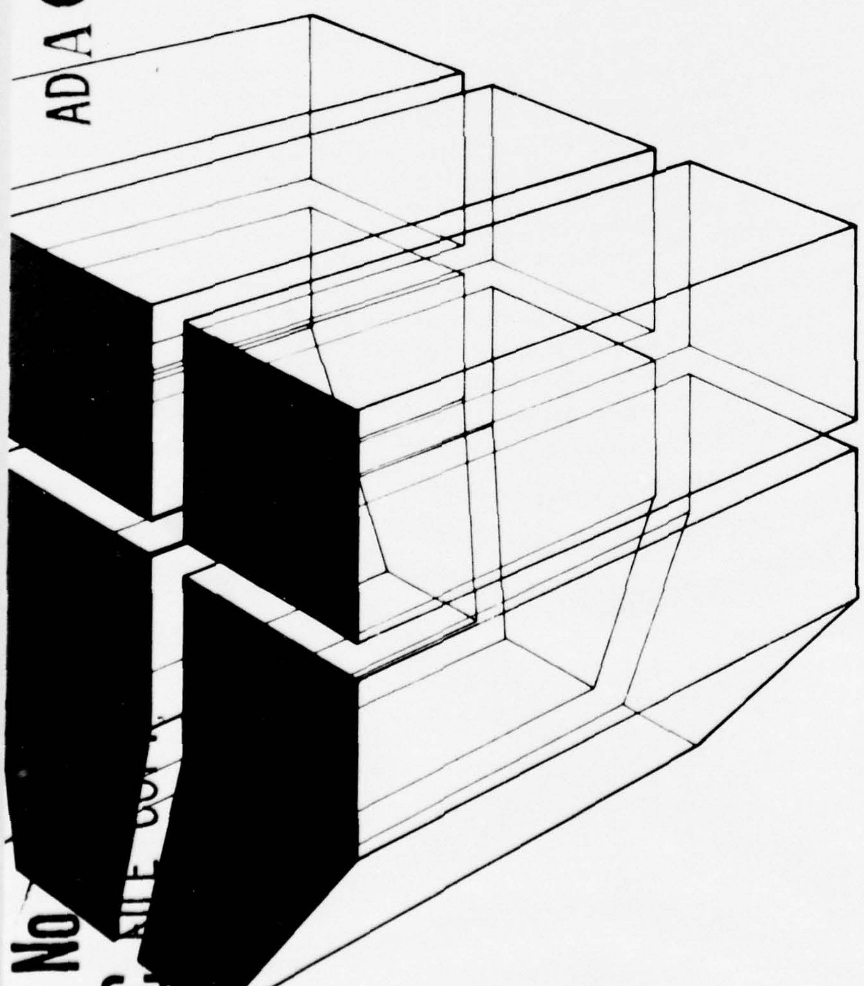
END
DATE
FILMED
9-77
DDC

construction
engineering
research
laboratory

12

TECHNICAL REPORT M-221
July 1977

EVALUATION OF THE CORROSION RESISTANCE OF ALTERNATE REVETMENT WIRE FABRIC MATERIALS IN THE LOWER MISSISSIPPI RIVER



by
E. P. Cox
C. G. Chen

CERL

Approved for public release; distribution unlimited.

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER CERL-TR-M-221	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) EVALUATION OF THE CORROSION RESISTANCE OF ALTERNATE REVETMENT WIRE FABRIC MATERIALS IN THE LOWER MISSISSIPPI RIVER.		5. TYPE OF REPORT & PERIOD COVERED FINAL rept., 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) E. P. Cox C. G. Chen		8. CONTRACT OR GRANT NUMBER(s) Vicksburg Dist. IAO 3152 New Orleans Dist. IAO LMNED-75-22 Memphis Dist. IAO LMMED-73-3
9. PERFORMING ORGANIZATION NAME AND ADDRESS CONSTRUCTION ENGINEERING RESEARCH LABORATORY P.O. Box 4005 Champaign, IL 61820		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS U.S. ARMY CORPS OF ENGINEERS Lower Mississippi Valley Division P.O. Box 80, Vicksburg, MS 39180		12. REPORT DATE Jul 1977 13. NUMBER OF PAGES 61
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) 12 62p.		15. SECURITY CLASS. (of this report) Unclassified 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

Copies are obtainable from National Technical Information Service
Springfield, VA 22151

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

revetment mattresses
wire fabric materials
corrosion resistance

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report presents the results of a study of the corrosion resistance and strength of alternate fabric materials for use in articulated concrete revetment mattresses to be placed on the lower banks of the Mississippi River. Three groups of materials—stainless steels, bimetallics, and organically coated low-carbon steels—were evaluated based on short-term electrochemical laboratory tests, laboratory sensitization evaluations, and exposures of up to approximately 4 years in freshwater and 15 months in brackish water.

Block 20 continued.

All the stainless steels tested (AISI 201, AISI 301, Armco 18-2, AISI 430, and AM 363) have sufficient strength and corrosion resistance in freshwater to qualify them as substitute wire fabric materials. However, only AISI 301 and AISI 201 evidenced sufficient corrosion resistance in brackish water for the period tested. Additional test data are needed to evaluate their overall corrosion resistance. In addition, all the stainless steels tested were found to be unsuitable for welded use in brackish water environments.

The bimetallic materials evaluated (Copperweld* and galvanized steel) performed satisfactorily with respect to corrosion resistance, although silt covering enhanced the resistance. The galvanized wire, however, has inadequate adherence of the zinc to the steel when deformed. The copperclad wire exhibited extremely rapid corrosion whenever the copper cladding was ruptured. More data are needed to evaluate the resistance of the bimetallic materials in salt water.

Of the organic coatings evaluated—VMCH (a vinyl resin), polyvinyl chloride, and polyethylene—only VMCH failed to provide adequate corrosion resistance for carbon steel wire in the Mississippi River. However, handling difficulties preclude use of these materials unless handling equipment is extensively modified.

*Copperweld is a trademark of Copperweld Corporation.

FOREWORD

This investigation was conducted for the U.S. Army Corps of Engineers Lower Mississippi Valley Division (LMVD). Funding was provided under the following Intra Army Orders (IAO): Vicksburg District IAO 3152, dated 15 October 1975; New Orleans District IAO LMNED-76-22, dated 6 October 1975; and Memphis District IAO LMMED-73-3, dated 7 October 1975. The LMVD Technical Monitor was Mr. J. Graham, LMVED-C.

The study was performed by the Metallurgy Branch (MSM), Materials and Science Division (MS), of the U.S. Army Construction Engineering Research Laboratory (CERL). CERL personnel directly involved in this study were Mr. J. Aleszka, Dr. C. G. Chen, Mr. E. Cox, Mr. C. Hahin, and Dr. R. Heidersbach.

COL J. E. Hays is Commander and Director of CERL and Dr. L. R. Shaffer is Technical Director. Dr. G. R. Williamson is Chief of MS and Dr. A. Kumar is Chief of MSM.

CONTENTS

TABLES

FIGURES

FIGURES (contd)

EVALUATION OF THE CORROSION RESISTANCE OF ALTERNATE REVETMENT WIRE FABRIC MATERIALS IN THE LOWER MISSISSIPPI RIVER

1 INTRODUCTION

Background

The U.S. Army Corps of Engineers has been successfully revetting the lower banks of the lower Mississippi River with articulated mats for many years. The revetments are composed of wire fabric (Figure 1) cast into concrete slabs to form articulated units (Figure 2). These units are assembled to form a concrete mattress of the desired length and width. These mattresses are then secured to the prepared river banks with steel cables and placed as shown in Figure 3. The amount of wire required for the annual revetment program is between 80 and 170 million linear feet (24 to 52 million meters).

The wire used in the revetment fabric must possess corrosion resistance and high strength. Initially, only two materials were accepted for this application: American Iron and Steel Institute (AISI) 301 stainless steel, and copper-clad carbon steel—specifically Copperweld* wire. However, the rising costs of nickel and copper and recent technological advances in new materials have prompted investigations of the possible existence of other, less costly materials which can meet the same requirements. Acceptance of additional materials would increase the number of wire fabric suppliers, thereby further reducing costs. As an initial result of these tests, the specifications for the fabric were expanded to include stainless steels AISI 201, AISI 430, AM 363, and Armco 18-2. Sixty-six hundred squares of AISI 201 are now scheduled to be furnished under an existing fabric contract.

Objective

The objective of this study is to evaluate candidate wire fabric materials as alternatives to Copperweld and AISI 301 stainless steel in articulated concrete revetment mattresses. The purpose of the phase of the study documented in this report was to assess the corrosion resistance and strength of alternate materials based on short-term electrochemical laboratory tests, laboratory sensitization evaluations, and exposures of up to approximately 4 years in freshwater and 15 months in brackish water.

*Copperweld is a trademark of Copperweld Corporation.

Approach

This study was conducted in four phases: candidate material selection and screening, exposure tests, sensitization evaluation tests, and laboratory corrosion assessment tests.

Material Selection and Screening

Three classifications of wire fabric materials were evaluated—stainless steels, bimetallics, and organic coatings on plain carbon steel. Candidate materials from probable future suppliers were selected and screened for compliance with the established mechanical properties specified for revetment fabrics,[1] as listed in section 2 of the appendix. Except for the galvanized wire, which failed the wrap test, only materials meeting the requirements were selected for further study. A standard low-carbon steel and the materials currently permitted in the specification were also tested to provide data for comparison. Chapter 2 presents information on the specific materials tested, as well as background information on the corrosion resistance of the three material classifications studied.

Exposure Tests

Since the best method of evaluating a material's corrosion resistance to a specific environment is to subject it to that environment, corrosion tests were made in the Mississippi River. The selected materials were fabricated into specimen blocks and exposed to the Mississippi River for time intervals ranging from 1 to 55 months. The exposures were made at Delta Point, LA (near Vicksburg, MS) and a site near New Orleans. The Delta Point samples were lost in the 1973 spring floods. Additional wire specimens, including some that were spot-welded, were prepared and exposed in a brackish water site in the Michoud Canal located near New Orleans.

After exposure for the desired time, the specimens were removed and returned to the U.S. Army Construction Engineering Research Laboratory (CERL) for evaluation. Results were compared with those for the standard low-carbon steel and the materials currently permitted in the wire fabric specification.

[1] *Specifications for End Twist Wires (Wire Forms) and Straight Wires*, Solicitation No. DACW66-70-R-0050 (Corps of Engineers Memphis District, 1973).

Chapter 3 describes specimen fabrication and the evaluation procedure in detail and presents the results of the exposure tests.

Sensitization Evaluation Tests

Sensitization of stainless steel is a localized corrosion attack generally associated with the depletion of chromium in the heat-affected zone of a welded component. The areas adjacent to the grain boundaries are attacked, leading to failure. To determine the sensitization resistance of the stainless steels, as-received, welded, and intentionally sensitized wires were tested using the 65 percent boiling nitric acid or Huey test. Chapter 4 details this procedure and the results obtained.

Laboratory Corrosion Assessment Tests

Laboratory tests were also required to adequately characterize the materials' corrosion resistance and provide information needed to permit rational comparison of the corrosion characteristics of different materials. The corrosion resistance of the stainless steels was studied using the electrochemical method in the laboratory under various environmental conditions. Chapter 5 describes this method and the results of the tests.

2 MATERIALS

Table 1 lists the materials tested and their suppliers, and Table 2 gives price information. The following sections list the specific materials evaluated in each of the three material classifications and discuss general characteristics of the corrosion behavior of the material types.

Stainless Steels

The stainless steels of interest in this project were low-cost, primarily low-nickel, stainless steels. Three austenitic stainless steels (AISI 201, AISI 301, and Armco 18-2), one ferritic stainless steel (AISI 430), and one martensitic stainless steel (AM 363) were chosen. (AISI 301 is currently used in revetment fabrics.) Table 3 gives the chemical compositions of the stainless steels.

Stainless steel seems to be an attractive material in terms of long-term corrosion resistance and ease of fabrication by conventional methods. The corrosion resistance of stainless steels has been attributed to the formation of an adherent, passive surface layer.[2] However, corrosion occurs whenever there is a breakdown in this passive film.

Pitting, the most common type of corrosion in stainless steels, generally occurs in high-chloride environments. Pitting is a self-initiated attack, characterized by severe localized corrosion. The susceptibility of a stainless steel to pitting is reduced by the addition of nickel and molybdenum; the higher nickel austenitic stainless steels are the most resistant.[3]

Other types of corrosion that attack stainless steels include crevicing, stress corrosion, and intergranular corrosion after sensitization. Crevice attack generally occurs as a result of either oxygen depletion due to accumulation of organic material on the surface, or the presence of a stagnant environment induced by geometry. Loop-ended specimens (described in Chapter 3) were used in an attempt to form a stagnant layer in the region where the wire contacted itself. Stress corrosion cracking, which generally occurs in highly stressed components in an aggressive environment, has been found to be a problem with stainless steels in saltwater environments; however, no stress corrosion tests were conducted in this study.

Bimetallic Materials

Bimetallic materials are widely used where corrosion resistance is required. The bimetallics chosen for evaluation were carbon steels clad with either copper or zinc. The zinc-clad specimen, which was used even though it failed the wrap test, was U.S. Steel Type C galvanized wire, and the copper-clad wire was the Copperweld material currently in use for revetment fabrics. A standard low-carbon steel was also tested to provide data for comparison.

In the copper-clad steel, the copper is used as a protective coating for the steel. Due to a difference in electrochemical potential, however, this combination can cause rapid corrosion where the underlying steel is exposed. The zinc coating, on the other hand, inhibits corrosion in two ways: by protecting the surface of the steel, and by corroding sacrificially, thereby cathodically protecting the steel surface. Thus, although none of the galvanized wires survived

[2] L. L. Shreir, *Corrosion*, Vol 1 (John Wiley and Sons, 1963), pp 3.55-3.57.

[3] H. H. Uhlig, *Corrosion and Corrosion Control* (John Wiley and Sons, 1963).

the wrap test with their zinc coating intact, the zinc still offered protection.

Organic Coatings

Covering steel wire with organic coatings is a good method of producing a high-strength, corrosion-resistant product. Of particular interest are the polymer coatings, which are impervious to electrochemical corrosion, do not deteriorate, and generally do not react with the product they coat. However, for organic coatings to be practical for fabrication of wire fabrics, they must:

1. Inhibit corrosion of steel wire in both fresh- and brackish water environments
2. Be easily applied
3. Be easily fabricated
4. Be nonporous
5. Have good adherence to steel
6. Meet physical requirements for handling and launching
7. Be durable
8. Be economical in terms of initial cost and application.

Most of the organic coatings available meet these criteria except for adherence and the physical requirements stated in the appendix. Three coatings which could possibly meet the above requirements were found—polyvinyl chloride (PVC), polyethylene, and VMCH (a proprietary vinyl resin coating of Union Carbide Company). The PVC and VMCH coatings are applied by dipping the component into the liquid coating after fabrication and letting the amount that adheres cure on the surface. After curing (drying), the coating is ready for use. Republic Steel's polyethylene coating, on the other hand, is extruded onto the wire before fabrication. Prior to extrusion, the steel wire surface is abraded and covered with a mastic undercoating.

3 EXPOSURE TESTS

Specimen Fabrication and Placement

Two sets of wire segments, approximately 13 in. (330 mm) long, were cut from each material. One set of each material had the wires looped about themselves at one end while the other set was left straight. The VMCH organic coating was applied at CERL, while the PVC- and polyethylene-coated wires were procured already coated. All coatings were applied prior to casting. The PVC-coated specimens consisted of rectangular sections cut from mesh, with the severed ends left open to expose the steel. The PVC coating was generally nonuniform, ranging in thickness from 0.010 to 0.013 in. (0.25 to 0.33 mm), with the top surface thinner than the bottom. Large drips were present in some instances. The thickness of the polyethylene coating was nominally 0.028 in. (0.71 mm) and was extremely uniform. The quality of the coating was excellent. The thickness of the VMCH coating ranged from 0.006 to 0.008 in. (0.15 to 0.20 mm) and was very uniform; however, entrained air bubbles were present. The VMCH coating, although apparently brittle, survived the tensile tests.

The wire specimens were then cast into 6 in. × 6 in. × 36 in. (152 mm × 152 mm × 0.9 m) concrete blocks. Table 4 gives the composition of the concrete, which was alkaline (pH 12) and may have been somewhat porous, since it was not vibrated during casting. The wires were embedded up to about one-half their length. Wires with looped ends were set so the loop was exposed to the water, as shown in Figure 4.

The blocks containing the wires were placed in racks (Figure 5) and lowered into the river at the two test points. Due to late arrival of some samples, all exposures did not begin at the same time. The first group, consisting of carbon steel, AISI 301, Copperweld, AISI 430, galvanized steel, polyethylene-coated wire, PVC-coated wire, and VMCH-coated wire, began exposure in May 1972. The second group, containing carbon steel, AISI 301, Copperweld, AISI 201, Armco 18-2, and AM 363, began exposure in November 1972. To date, the specimen blocks have been exposed for periods of 1, 3, 6, 12, 18, 24, 36, 43, and 55 months. Table 5 gives the date of immersion and length of exposure for each specimen block.

Evaluation Procedure

After exposure for the desired time, the specimen blocks were removed and sent to CERL for evaluation. Corrosion resistance was first evaluated by macroscopically examining the condition of the wires just after removal from the water. The remaining silt and organic matter were removed, and the wires were examined for large pits, crevices, or areas

of localized attack. The coatings were also checked for abrasion, cross-sectional attack, and general deterioration.

The wires were then removed from the concrete blocks for further examination. The entire length of each wire was fully examined at a low magnification (10x) for pits anywhere along the length, crevice attack in the loop-ended specimens, preferential attack where the wire specimen entered the concrete or at the severed ends, and formation of corrosion products at the severed ends of the bimetallic and organically coated wires. In addition, the organic coatings were checked for porosity and resistance to splitting where corrosion products had accumulated.

Specimens with peculiar appearances, particularly the galvanized and carbon steel wires, were examined in the scanning electron microscope (SEM). A visual examination was also performed, primarily to discern the presence of large-scale corrosion and whether it occurred at a particular location, such as at the stagnant layer in the looped-end specimens.

Where corrosion was observed, the specimens were sectioned for metallographic study. This technique was used extensively to assess the presence and rate of attack in the bimetallic wires.

Measuring the change in electrical resistance that occurred over a time interval was the second method used to determine the presence of corrosion. Resistance measurements have the advantage of simplicity of technique and reproducibility of results. Changes that arise from corrosion result from a change in the wire cross section. Both localized corrosion and uniform attack cause an increase in resistance. In general, corrosion products have a much higher electrical resistivity than do the metals on which they form and therefore do not interfere with resistance measurements.[4] The coatings were removed from the specimens coated with organic materials, and resistance was measured with a milliohm meter along a 4-in. (102-mm) length of wire which included the region of wire emerging from the concrete block. Resistance after exposure was then compared with resistance of unexposed wires.

The third method for determining if corrosion had occurred was measurement of changes in mechanical properties. This method is particularly important in the design of the structure if there is a time-related loss of strength or ductility. The method will reveal the presence of corrosion undetected by other measurements, since corrosion anywhere along the length affects the mechanical properties, and failure always occurs at the weakest point. Mechanical properties also indicate the severity of corrosion, since there is initially a decrease in ductility but little reduction in strength. As the corrosion process continues, the ductility remains low and the strength of the component starts to decrease.[5]

After macroscopic examination, the wires were tested in tension to failure. The maximum load tensile strength, reduction in area, and the strain at failure were measured. The fracture surfaces were then inspected and the location of the fracture noted. The behavior of the coatings on the bimetallic and organically coated specimens during testing was also observed.

Results

Tables 6 and 7 present the resistance measurements for the specimens in freshwater and brackish water, respectively; Tables 8 through 17 give the results of the mechanical property tests.

Stainless Steels

AISI 201. Corrosion data on AISI 201 stainless steel exposed to the Mississippi River have been obtained for 6-, 18-, 30-, 36-, and 43-month exposures. Although the wires were heavily fouled with organic matter, macroscopic and microscopic examinations indicated no pitting, even on the ends where the wire samples were severed. Examination of looped specimens showed no indication of crevice attack.

No significant change in resistance occurred during these exposure intervals (Table 6).

During testing, this material did not exhibit a yield point and strain-hardened to failure; consequently, the tensile strength was equal to the failure strength (Table 8). In the exposed specimens, tensile strength did not decrease with exposure time. The reduction in area was about the same as for unexposed wire. Fracture generally occurred along the exposed section.

[4]F. A. Champion, *Corrosion Testing Procedures* (John Wiley and Sons, 1965), p 239.

[5]Champion, p 229.

Samples of AISI 201 exposed in the Michoud Canal brackish water site were retrieved after 15 months of exposure. When removed from the water, the specimens were heavily encrusted with marine life. The specimens were cleaned and examined visually; no indications of corrosion were found. The resistance measurements and mechanical properties tests confirmed this finding.

Spot-welded specimens of AISI 201 were also exposed in the Michoud Canal brackish water site. After cleaning, extensive corrosion attack could be seen in the weld region (Figure 6); this corrosion progressed into the interior of the wire. No corrosion attack was seen elsewhere.

AISI 301. Freshwater corrosion data for AISI 301 have been obtained for 1-, 3-, 6-, 12-, 18-, 24-, 30-, 36-, 43-, and 55-month exposures, including tests initiated in the spring and fall. The longer term exposure samples were heavily encrusted with silt and organic matter. However, neither macro- nor microscopic examination revealed any pitting. No crevice attack was observed in the loop-ended specimens.

The resistance data (Table 6) indicate no significant change in resistance with time of exposure.

The tensile tests (Table 9) revealed that AISI 301 is a highly strain-rate-sensitive material in which ductility can be greatly increased at very low strain rates. AISI 301 did exhibit a yield point which exceeded its capability to work-harden; consequently, the yield point was equivalent to the tensile strength while the fracture strength was somewhat lower. There was no change in reduction in area with time; the fracture locations were sufficiently random to preclude localized attack.

The brackish water specimens of AISI 301 were heavily covered with marine life when removed. The specimens were carefully examined after cleaning, but no corrosion attack was seen. No loss in strength or ductility had occurred after 15 months of exposure, and the electrical resistance values across the test section were unchanged.

Spot-welded specimens of AISI 301 were heavily corroded in the heat-affected zone (just outside the weld region). Close examination of this area revealed that the interior metal was either missing (corroded away) or heavily oxidized. The weld regions were lightly attacked. No corrosion was observed elsewhere.

Armco 18-2. Results have been obtained for Armco 18-2 after freshwater exposures of 6, 18, 30, 36, and 43 months. No surface deterioration in the form of either pitting or crevice attack was found on the wire surfaces. Resistance did not change with exposure time, indicating a lack of corrosion.

The tensile tests (Table 10) showed that this alloy has low ductility and essentially zero reduction in area, either because the wire samples were heavily cold-worked, or because of their small diameters. The lack of ductility could result in the material failing the mechanical properties specifications.

There was no loss of tensile strength due to exposure, nor was there a decrease in ductility. No change in reduction in area as a function of exposure time was observed.

Specimens of Armco 18-2 exposed to the Michoud Canal brackish water environment showed minor corrosion pitting on the surface after 15 months of exposure. This indication was verified by a slight elevation in electrical resistance along the test section. The tensile test on a straight wire specimen showed a significant 48 percent loss in strength.

Spot-welded specimens of Armco 18-2 were completely corroded through in the heat-affected zone (Figure 6) after 15 months of exposure in brackish water. Corrosion extended into the weld, leaving only a hollow wire surrounded by an outer skin of uncorroded material.

Armco 18-2 is therefore not suitable for use in saltwater environments.

AISI 430. Data on AISI 430 have been obtained after exposure in freshwater for periods of 1, 3, 6, 12, 24, 36, and 55 months. Many of the specimen blocks containing this wire were heavily encrusted with silt and covered with organic matter from the river. Macroscopic examination showed the surfaces to be free of pitting and crevice attack for each exposure. This observation is supported by the resistance data for this material (Table 6), which show no significant change in resistance after exposure.

The tensile tests performed on this material (Table 11) showed that it work-hardens to failure. No yield point was observed in the standard tests, nor was any significant change in tensile strength observed. No change in ductility or reduction in area occurred. Fracture generally occurred either along the length

exposed to the water or at the concrete-water interface.

Exposure of AISI 430 specimens in brackish water resulted in obvious corrosion after 15 months. Figure 7 shows surface pitting and deep corrosion into the interior of AISI 430 wire samples. Figure 8 shows a closeup of the interior corrosion. Because the severe corrosion attack was away from the 4-in. (101.6-mm) test section, no change in electrical resistance was noted. The tensile test results (Table 11) show a 38 percent loss in strength and a complete loss in ductility.

Spot-welded specimens of AISI 430 (Figure 6) were completely corroded through after 15 months of exposure to brackish water. The worst corrosion attack occurred in the heat-affected zone just outside the weld. The weld itself was also heavily corroded, and other regions along the length of the wire were corroded and porous.

These results indicate that AISI 430 is not suited for use in saltwater environments.

AM 363. Freshwater corrosion data on AM 363, a proprietary alloy of Allegheny-Ludlum, have now been gathered for 6-, 18-, 36-, and 43-month exposures. Neither pitting nor crevice attack were detected on the wire surface after exposure. Resistance (Table 6) did not change with time, confirming the visual inspection results.

The tensile tests (Table 12) indicated no loss in tensile strength during the exposure. Fractures occurred in random locations in the wires.

AM 363 samples exposed in the brackish water environment were heavily encrusted with marine life and silt. After cleaning, deep pits could be seen at sites where barnacles and clams had attached themselves. The wires were most heavily corroded at the clipped end exposed in the salt water. The interior of the wire was almost completely hollowed out, giving the wire a bonelike appearance (Figure 9). A significant loss of strength was detected in the tensile test (Table 12). No major change in electrical resistance was noted in the normal test section; however, this was an artifact of the test method, since the heavily corroded region was outside the normal test section. The resistance was much greater in the heavily corroded region.

AM 363 specimens which were spot-welded and exposed in the brackish water were also heavily corroded (Figure 6). Close inspection of the wires after cleaning indicated severe corrosion in the weld region and complete loss of material in the heat-affected zone close to the weld. The remainder of the wire along the length away from the weld was also heavily corroded and had a porous (spongelike) appearance.

These results indicate that AM 363 is definitely not suited for use in salt water.

Bimetallic Materials

Low-Carbon Steel. Plain carbon steel wire was tested solely as a standard for comparison with the bimetallic materials, not as a candidate wire fabric material. Corrosion of the carbon steel occurred after a short exposure time in both fresh- and brackish water. Microscopic examination of freshwater specimens exposed for 1 month revealed the presence of rust along the length exposed to the water. After longer time periods, the rust was more prominent, and accelerated attack was observed at the region where the wire emerged from the concrete in both fresh- and brackish water environments. The accelerated corrosion attack resulted in the formation of a necked region (Figure 10). It was estimated that this necked region could be completely corroded away in approximately 2 years. High-magnification examination of the necked region revealed that the corrosion occurred in layers oriented along the length of the wire. Figure 11 shows an SEM photograph of this region. In contrast to the rapid attack that occurred along the length exposed to the water, no corrosion was observed along the section embedded in concrete. This was attributed to the alkalinity of the concrete.[6]

Electrical resistance measurements on the plain carbon steel wires exposed in freshwater showed little change in the first 3 months. After 18 months of exposure, however, the resistance had doubled. The resistance increased rapidly as the wires necked, becoming infinite in wires which had corroded completely through. Similar results were noted for specimens exposed in brackish water.

The tensile tests showed that the material exhibited a definite yield point, and work-hardened to the point of fracture. The load-carrying capacity

[6] H. H. Uhlig, *Corrosion and Corrosion Control* (John Wiley and Sons, 1963), pp 85-92.

decreased rapidly for exposure times greater than 12 months and decreased to zero in about 2 years as a result of corrosion (Table 13). A similar loss in ductility occurred; after 18 months of exposure, the ductility had decreased from about 5.6 percent to 1.8 percent, and from 18 to 24 months it approached zero. Tensile tests were not conducted on the carbon steel specimens exposed in brackish water, but similar results are expected.

Galvanized Low-Carbon Steel. Data on the galvanized steel have been obtained for freshwater exposures of 1, 3, 6, 12, 24, 36, and 55 months and brackish water exposure of 15 months.

At high magnification, deep pits were seen in the exposed galvanized specimens, especially in the region where the wire emerged from the concrete; Figure 12 shows this section of a wire exposed for 1 year. However, pitting of the zinc surface layer was also found in unexposed wires. Figure 13 is a low-magnification photograph of unexposed wire; Figure 14 shows a high-magnification photograph of one of the pits. It is believed that in some instances these pits extended to the surface of the carbon steel wire. Examination of the zinc surface layer after exposure indicated that the pits initially present will deepen and open until the zinc surface layer becomes insufficient to inhibit corrosion of the exposed steel. The projected life of the galvanized wire is approximately 8 to 10 years.

The electrical resistance measurements (Table 6) showed a slow increase with exposure time. Since the zinc has a greater conductivity than the steel, the resistance change arises from the dissolution of zinc rather than corrosion of the steel. Similar data were obtained for both fresh- and brackish water exposure specimens.

Data for the tensile tests (Table 14) indicate no loss of tensile strength with time and no decrease in ductility in freshwater up to 36 months. However, a 20 percent loss in tensile strength was seen in the freshwater specimen exposed for 55 months. Although tensile strength, ductility, and reduction in area did not change appreciably up to the 55-month exposure, there may have been a mild, localized attack at the region where the wire emerged from the concrete, since tensile fractures occurred predominantly at the interface. Earlier tests[7] have shown that very little deterioration occurs after 2 years when the zinc wires are covered with silt, but that without the protective silt covering, the wires corrode extensively after 2 years of exposure to the Mississippi River. The corrosion rate is anticipated to be higher in the brackish water, but longer exposures are necessary before a definite conclusion can be reached.

[7] *Report on Corrosion Test of Metals in the Mississippi River* (Corps of Engineers Memphis District, May 1939).

Copperweld Steel. Data on the Copperweld wire have been obtained for freshwater exposures of 1, 3, 6, 12, 18, 24, 30, 36, 43, and 55 months as well as 15 months of brackish water exposure. Examination of the surfaces of the wire test samples after exposure revealed very little deterioration anywhere along the length, except in the brackish water exposure specimens. No pits were found in the straight wires, nor were crevices found in the looped-end specimens. Rapid corrosion was observed at the ends where the steel core was exposed (Figure 15). The depth of corrosion into the wire was measured (Table 18) and plotted versus time (Figure 16). The freshwater specimens initially exposed in November appeared to have a slightly higher corrosion rate. The corrosion rate of the brackish water exposure specimens was approximately double that of the freshwater specimens. Based on these data, a rupture in the copper cladding would lead to corrosion completely through the steel core in approximately 6 months in freshwater and less in brackish water. Localized corrosion of the copper cladding was seen at the concrete-water interface of specimens exposed in the brackish water (Figure 17).

The electrical resistance measurements of the exposed wires (Table 6) showed a slight increase in resistance with respect to time of exposure. The cause of the increase is believed to be a uniform loss in coating thickness, since the copper is much more conductive than the steel.

The mechanical property tests on the Copperweld wire (Table 15) showed a slow loss of strength with time in freshwater. Reduction in area did not change appreciably with time of exposure, and tensile fractures occurred at random locations along the wire. Insufficient data are available to draw any conclusions on the strength loss of copper-clad specimens in brackish water.

Organic Coatings

PVC-Coated Wires. Data for the PVC-coated wires have been obtained for freshwater exposures of

1, 3, 6, 12, 24, and 36 months and for brackish water exposure of 15 months. Examination of the specimen surfaces after exposure revealed some porosity in the coating, which was probably present when the coating was applied. The porosity did not extend through the coating to the steel wire. Examination of the exposed ends showed rust accumulation; after 18 months in freshwater, the volume expansion of the corrosion product was sufficient to split the coating. Removal of the coating from the steel underwire revealed rust on the steel near the exposed ends, due to water seepage under the coating. The quantity of rust under the coating did not appear to be a detriment to the use of this coating.

The wires' electrical resistance (Table 6) did not change with time. The tensile tests (Table 16) indicated that no loss of strength or ductility occurred. There was no change in reduction in area, and the location of the tensile fractures was random. Tensile and resistance tests were not conducted on the specimens exposed in the brackish water.

Polyethylene-Coated Wires. Polyethylene-coated wire specimens were evaluated after freshwater exposure periods of 1, 3, 6, 12, 24, and 36 months and after 15 months exposure in brackish water. Large amounts of rust were observed at the end where the steel wire was exposed. This accumulation has not yet been sufficient to cause the coating to split. Examination of the surface of the coating showed no deterioration. When the coatings were removed from the specimens, the wire beneath was free of corrosion and there was little penetration of rust into the wire. The mastic undercoating was intact in all cases and no seepage under the polyethylene was found.

The resistance data accumulated to date show no change with exposure time. The results of the tensile tests (Table 17) showed no change in tensile strength or ductility for any of the exposed specimens. No change in reduction in area with exposure time was evident, and the tensile fractures tended to occur predominantly along the length exposed to water. The resistance change and tensile strengths of the wire specimens exposed in brackish water were not determined.

Problems were experienced in preparing the polyethylene-coated wires for field testing in November 1974. The wires were cast into five 25 ft × 4 ft (17.62 m × 1.22 m) "squares" to be sunk into the Mississippi River. After the concrete had cured at the casting yard, the squares were transferred by barge to the assembly area where they were to be connected to other squares to form mattresses. The squares were placed on the barge using a rectangular frame connected to a crane. The frame, which has an outcrop of 20 fingers, fits over a stack of 13 squares and lifts them simultaneously by their outside wires. During the transfer, it was noticed that the fingers did not grab each square individually, but transferred most of the weight to the wires in the bottom four squares. At the end of this operation, a number of gouges (one of them about 3 in. [76 mm] long) were observed in the coating, exposing the bare metal. While at the assembly area, the squares' end loops were tied together by hand while the longitudinal bracket wires were tied to a launching cable using a pneumatic tying tool. After tying had been completed, more breaks in the coating were found. As a result of these breaks, the polyethylene-coated wire was judged unsuitable for use in revetment operations using current handling equipment. Since the polyethylene coating was the hardest of the three organic coatings tested, it was judged that the PVC and VMCH coatings would also be too soft to survive current handling methods.

VMCH-Coated Wires. The VMCH coating was found to be porous in some spots after 18 months of exposure in freshwater; specimens exhibited cracks in the coating and corrosion beneath. The coating may have degraded as a result of being applied too thinly, or it may have been scratched during specimen preparation. Due to this rapid deterioration, evaluation ceased after the 18-month exposure, and the VMCH-coated specimens were not exposed to the brackish water environment.

4 SENSITIZATION EVALUATION TESTS

Procedure

Sensitization of stainless steel is a form of intergranular corrosion caused by changes in the vicinity of the grain boundaries induced by precipitation of carbides or interstitials which occurs within specific temperature ranges.[8] Significant dwell time in these temperature ranges may occur during cooling of the welded wire.

To evaluate whether the welded stainless steel wires were sensitized, the 65 percent boiling nitric

[8] M. G. Fontana and R. D. Greene, *Corrosion Engineering* (McGraw-Hill, 1967), pp 58-67.

acid or Huey test (ASTM Standard A 262-70, Practice C)[9] was used. This quantitative test, which compares weight loss to surface area, indicates the susceptibility of the alloy to attack because of chromium carbide precipitation.

The standard test method consists of immersion of steel samples (weighed, cleaned, and dimensioned) in boiling reagent nitric acid (HNO_3) for five 48-hour periods with changes in fresh acid every period. (In this investigation, a single 48-hour period was used for evaluation.) Acid solutions are placed in 1000-ml Erlenmeyer flasks with cold-finger condensers. After each period, samples are rinsed, ultrasonically cleaned in acetone, and weighed on an analytical balance.

Specimens tested consisted of stainless steel wires welded using various heat inputs and numbers of cycles, as-received wire stock, and wires intentionally sensitized by laboratory heat treatment. To insure compositional uniformity, as-received sections were taken from the welded wires away from the welded region. The austenitic steels were sensitized at 750°C for 2 hours and then water-quenched. The ferritic and martensitic stainless steels were sensitized for 1.5 hours at 900°C and immediately water-quenched.[10] All specimens were tested separately.

Corrosion rates were calculated using the formula:

$$\frac{\text{mils}}{\text{yr}} = 82.77\frac{W}{DAt} \quad \text{or} \quad \frac{\text{mm}}{\text{yr}} = 2.7\frac{W}{DAt}$$

where W = weight loss, mg
D = density of alloy
A = area, cm^2
t = time, hour (48 hours/boiling period).

Results

Table 19 summarizes the results of the Huey tests. The corrosion rates of the sensitized samples were all higher than those of the as-received samples, except for AM 363. This alloy has a higher corrosion rate than the others because it has only about 12 percent chromium and has a martensitic microstructure. The corrosion rates of the welded sections were slightly greater than those of the as-received specimens of the same alloys, particularly for Armco 18-2 and AISI 201. On the other hand, little difference between the as-received and as-welded corrosion rates was found for alloys AISI 301 and AISI 430.

The sensitization data were based solely on surface corrosion and may not reflect the lifetime corrosion rate. Since these were only screening tests and were much more severe than Mississippi River waters, the results obtained indicate only relative sensitization resistance. The actual sensitization vulnerability of these alloys in fresh- or brackish water must be obtained by actual field immersion tests or potentiodynamic investigations. However, the results do indicate that sensitization is not anticipated to be a problem in freshwater.

5 LABORATORY CORROSION ASSESSMENT TESTS

Procedure

The corrosion resistance of the stainless steels was studied in the laboratory using the electrochemical method under various environmental conditions.[11] The advantage of using the electrochemical technique in corrosion studies is that data concerning the corrosion behavior of a given material can be easily and quickly obtained in the laboratory. Good agreement between this method and the conventional weight loss measurement or field tests has been demonstrated.

The electrochemical technique involves two kinds of measurements. First, the corrosion current is measured over a very wide potential range to determine both the anodic and cathodic polarization behaviors. This type of test determines how easily a given stainless steel can be passivated and how stable the alloy is. This is important because the corrosion resistance of the stainless steels depends entirely on their capability to be passivated. Second, the free corrosion rate is measured by the linear polarization technique, in which the polarization resistance between the specimen and the electrolyte is determined. The corrosion rate of the stainless steels can

[9] "Detecting Susceptibility to Intergranular Attack in Stainless Steels," ASTM A 262-70, *1976 Annual Book of ASTM Standards*, Part 10.

[10] E. Cox, C. Hahin, and J. Aleszka, *Evaluation of Alternate Wire Fabric Materials for Articulated Concrete Mattresses*, Technical Report M-169/ADA018951 (U.S. Army Construction Engineering Research Laboratory, November 1975), pp 20-21.

[11] "Standard Reference Method for Making Potentiostatic and Potentiodynamic Anodic Polarization Measurements," ASTM 65-72, *1976 Annual Book of ASTM Standards*, Part 10.

then be calculated from the value of the polarization resistance.

In this study, specimens with a known surface area and a good surface were first prepared. The surface was polished to a 600-grit silicon carbide finish and cleaned. Each specimen was immersed in the electrolyte, and the open circuit potential was measured after it stabilized. Potential was then very slowly increased or decreased to about +1.60 or −1.20 V in reference to a saturated calomel electrode (SCE). All tests were conducted in accordance with ASTM Standard G 5-72. The linear polarization measurement was conducted similarly, except that the potential of the specimen varied slowly within ± 10 mV from its open-circuit potential. The slope of the potential vs current plot (which usually is a straight line) is related to the free corrosion rate of the material.

The galvanic coupling between the low-carbon steel and either copper (Copperweld) or zinc (galvanized steel) was also investigated in tap water. The open-circuit potentials for each set of materials—steel-copper and steel-zinc—and the current flowing between them when electrically coupled were measured to determine the extent of galvanic corrosion of copper-clad and galvanized steel. Usually, the coupling of two dissimilar metals changes their corrosion behavior significantly.

Results

Stainless Steels

Corrosion assessment data were obtained using a potentiostat and several electrolytes (corrosion environments). Figures 18 to 22 show the potentiodynamic polarization curves of the AISI 201, AISI 301, Armco 18-2, AISI 430, and AM 363 stainless steels in 1 N sulfuric acid (H_2SO_4) and 1 N H_2SO_4 + 1 M sodium chloride (NaCl) solutions. Figure 23 is a schematic diagram of the polarization behavior of stainless steels for use in interpreting these curves. All the stainless steels showed roughly the same active-passive transition in sulfuric acid, and the general shapes of the curves are similar, indicating that all the stainless steels studied have roughly the same corrosion behavior in this environment. The addition of salt to the solution clearly almost entirely destroyed the passivity in some cases, indicating that the protective film formed on the surface of the specimen during passivation was heavily attacked by the chloride (Cl^-) ions, resulting in severe pitting on the surface.

Figures 24 to 28 show the potentiodynamic polarization curves of the stainless steels in tap water and 3.5 percent salt (NaCl) water. Table 20 gives the composition of the tap water; the 3.5 percent salt water had the same composition plus 3.5 weight percent reagent-grade (NaCl). In the case of tap water, the passivation proceeded almost spontaneously, and no pitting was observed over a fairly wide potential range. Again all the stainless steels show roughly the same corrosion behavior. In the case of salt water, however, all the stainless steels were severely attacked, and pitting appeared on the surface.

Figure 29 shows the results of a typical linear polarization measurement for the AISI 301 stainless steel after the specimen had been immersed in the tap water for 7 days. The linear resistance, or the slope of the curve at the corrosion potential, can be related to the free corrosion rate by[12]

$$\text{corrosion rate (mpy)} = \frac{K}{RA}$$

where mpy denotes mils per year uniform corrosion, K is an electrochemical constant depending on the metal and corrosive, R is the resistance in ohms, and A is the area of the specimen in square inches. For stainless steels, the constant K is approximately the same in most environments. K was accurately determined by making a weight loss measurement; a piece of AISI 301 stainless steel of known area and weight was immersed in tap water for a known period of time and the weight loss was measured after the immersion. Based on this measurement, the constant K was determined to be equal to 600. Table 21 shows the results of linear polarization measurements for the AISI 201, AISI 301, AM 363, Armco 18-2, and AISI 430 stainless steels in tap water after immersion for 7 days. The corrosion rates decreased steadily initially, and stabilized after being immersed for a few days. The corrosion rates of all the stainless steels tested are extremely low. These low corrosion rates were confirmed by the fact that no deterioration of any of the stainless steels was detected over a period of 3 years in actual freshwater immersion tests. Thus, the corrosion resistance of all the stainless steels tested is approximately equal to that of the AISI 301 stainless steel. They are therefore qualified as alternative wire fabric materials for freshwater applications.

[12] *NACE Basic Corrosion Course* (National Association of Corrosion Engineers, 1971), p 3-17.

Bimetallic Materials

Galvanic coupling between low-carbon steel and copper or zinc was also studied in tap water to assess the corrosion behavior of Copperweld and galvanized steel. Table 22 shows the uncoupled corrosion potentials and the free corrosion rates of low-carbon steel, copper, and zinc in tap water. These data indicate that steel becomes an anode and corrodes sacrificially when coupled to copper, while zinc becomes an anode and cathodically protects steel when they are coupled.

Thus, although the galvanized wires' failure to survive the wrap test prescribed in the specification with their zinc coating intact accelerates the corrosion rate of the zinc, the steel is protected as long as the zinc is present. In contrast, copper-clad steel is only protected when the coating is intact.

The amount of accelerated corrosion or protection depends largely on the anode-to-cathode area ratio. With Copperweld, only a tiny fraction of the steel is usually exposed to the water, so that the area ratio is extremely small. This is a very unfavorable situation for the steel, which will corrode rapidly through contact with copper. To assess how rapidly such corrosion can proceed, the current flowing between electrically coupled steel and copper was measured for two different values of area ratio. Since the magnitude of the coupling current was found to be much larger than the exchange current, the corrosion rate of steel could then be calculated directly from the magnitude of the coupling current. The results (Figure 30) indicate that the corrosion rate of steel increases markedly when it is coupled to copper having a very large surface area. For galvanized steel, the anode-to-cathode area ratio is usually very large. The zinc can therefore effectively protect the exposed steel, and the corrosion rate of the zinc is not significantly affected by contact with the steel.

These studies indicate that Copperweld and galvanized steel will perform satisfactorily only when the copper coating is intact or when a large portion of the zinc coating is present. From the corrosion rate measurements, copper coating on the order of 0.006 in. (0.152 mm) thick should have a life of about 80 years, and zinc coating of the order of 0.004 in. (0.102 mm) thick should last about 10 years. However, silt covering, which usually occurs at the bottom of the river, can significantly increase the projected life. Depending on the degree of covering, such a silt layer can accomplish two things: (1) reduction of the general corrosion rates of copper and zinc, and (2) in the case of the copper-clad steel, significant reduction of the cathodic reaction on the copper surface, so that the effective area of copper (or cathode) is very small. Such an increase in the value of the anode-to-cathode ratio would result in the corrosion rate of steel no longer being accelerated. To substantiate this possibility, the corrosion potential of a piece of Copperweld recovered from the Mississippi River heavily coated with silt was measured in tap water. It was found that the open circuit corrosion potential dropped to about −0.4 V (SCE) instead of the usual value (+0.007 V) for bare copper (Table 22).

This effect of silt covering may be one reason why most of the copper-clad steel currently immersed in freshwater is still relatively uncorroded. This effect would also explain why inspection of Copperweld fabric materials initially placed in 1954 near Coochie, LA (river mile 317.6) indicated that the fabric was in good condition as long as it was continuously immersed in water and covered with silt, while rapid deterioration due to corrosion was seen in copper-clad anchoring cables in service for as little as 2 years on the river banks.

6 CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The susceptibility of stainless steel, bimetallics, and organically coated steel to corrosion in the freshwater Mississippi River above New Orleans and in brackish water is presently being evaluated. Analysis of specimens after approximately 4 years of exposure in freshwater and 15 months in salt water and results of laboratory electrochemical and sensitization tests have led to the following conclusions:

1. All the stainless steels tested have more than enough strength and corrosion resistance in the Mississippi River above New Orleans (freshwater environment) to qualify them as substitute wire fabric materials. The only stainless steel which may be questionable as a fabric material is Armco 18-2, which has good corrosion resistance but very low ductility.

2. Exposure tests of the stainless steels in brackish water showed that AISI 430, AM 363, and Armco 18-2 are unsuitable for use in this environment. Similar exposures of spot-welded stainless steel wires

resulted in severe sensitization and localized corrosion near the welds. All stainless steels tested are unsuited for welded use in brackish water environments.

3. The bimetallic materials evaluated performed satisfactorily with respect to corrosion resistance in freshwater; however, silt covering enhanced the corrosion resistance of some of these materials. Also, problems encountered during machine handling of these materials may cause a major change in the expected life of the component. The galvanized wire appears to be especially susceptible as a result of inadequate adherence of the zinc to steel, as evidenced by failure of the wrap test. Since the worst treatment of the wire fabrics occurs during handling in the casting yard, assembling into revetments, and launching, this could be a cause for rejection. Copper-clad steel wires exhibited extremely rapid corrosion whenever the copper cladding was ruptured. The results showed that through-thickness corrosion could occur within 6 months after exposure in freshwater and less in brackish water.

4. Except for VMCH, the organic coatings evaluated provide adequate corrosion resistance for carbon steel wire in the Mississippi River. However, the coatings are too soft to withstand the current handling methods. Major modification of the handling equipment is necessary before they can be a viable substitute for metallic wires.

5. Sensitization tests revealed that welding alloys AISI 201, AM 363, and Armco 18-2 could result in some localized corrosion attack in the weld region. Welded samples of AISI 301 and AISI 430 had corrosion rates similar to those of unwelded samples. Except for AM 363, furnace-sensitized samples had higher corrosion rates than as-received specimens.

6. Electrochemical corrosion tests indicated that the open circuit corrosion rates of the stainless steels in tap water are similar. The presence of chloride increases the corrosion rates substantially.

7. Galvanic coupling tests indicate that the corrosion rate of steel is accelerated through contact with copper. Zinc, on the other hand, can usually protect the steel effectively when the two are electrically coupled.

Recommendations

The following recommendations are based on the results and conclusions of this investigation:

1. A number of squares should be fabricated from AISI 201, AISI 430, AM 363, and Armco 18-2 stainless steel alloys and field tested in freshwater.

2. If the stainless steel squares perform satisfactorily in the field, the specification pertaining to the type of fabric material (Part II, Section 1-02) should be expanded to include all of the stainless steels examined in this study.

3. Modifications that would be required in the handling equipment in order to use the organically coated fabrics should be determined, and whether these modifications would be cost-effective when used in conjunction with organic coatings should be ascertained.

4. The zinc-coated wire should be considered unacceptable as a substitute fabric material unless the lifting and launching equipment are modified to minimize the flaking of the zinc coating.

5. The polyethylene-coated wire should be considered unacceptable as a substitute fabric material, unless handling modifications are made to eliminate stripping of the coating.

6. Research should be conducted to ascertain the effect of bimetallic junctions on the corrosion of the composite structure. Bimetallic junctions occur whenever copper-clad steel tie, wrap, and anchor wires are used with stainless steel wire fabric mats.

7. Electrochemical data should be obtained for the various candidate wire fabric materials. The electrolyte used should be Mississippi River water taken at various locations.

8. The effect and extent of silt covering as well as the effect of the anode-to-cathode ratio on the corrosion rate of wire fabric mat materials should be investigated to explain the rapid corrosion of copper-clad steel wires periodically wetted with water versus the slower corrosion rate observed in continuously immersed wire.

9. Additional new materials should be sought for use as mat fabric wire and for the wires. Table 23 contains a partial list of materials suitable for evaluation for either application.

REFERENCES

Champion, F. A., *Corrosion Testing Procedures* (John Wiley and Sons, 1965).

Cox, E., C. Hahin, and J. Aleszka, *Evaluation of Alternate Wire Fabric Materials for Articulated Concrete Mattresses*, Technical Report M-169/ADA018951 (U.S. Army Construction Engineering Research Laboratory, November 1975).

"Detecting Susceptibility to Intergranular Attack in Stainless Steels," ASTM A 262-70, *1976 Annual Book of ASTM Standards*, Part 10.

Fontana, M. G. and R. D. Greene, *Corrosion Engineering* (McGraw-Hill, 1967).

NACE Basic Corrosion Course (National Association of Corrosion Engineers, 1971).

Report on Corrosion Test of Metals in the Mississippi River (Corps of Engineers Memphis District, May 1939).

Shreir, L. L., *Corrosion*, Vol 1 (John Wiley and Sons, 1963).

Specifications for End Twist Wires (Wire Forms) and Straight Wires, Solicitation No. DACW66-70-R-0050 (Corps of Engineers Memphis District, 1973).

"Standard Reference Method for Making Potentiostatic and Potentiodynamic Anodic Polarization Measurements," ASTM G 5-72, *1976 Annual Book of ASTM Standards*, Part 10.

Uhlig, H. H., *Corrosion and Corrosion Control* (John Wiley and Sons, 1963).

Table 1

Materials and Suppliers

Material	Supplier
AISI 201 Stainless Steel	U.S. Steel
AISI 201 Stainless Steel	Central Steel and Wire Co.
Armco 18-2 STainless Steel	Armco Steel
AISI 430 Stainless Steel	Central Steel and Wire Co.
AM 363 Stainless Steel	Allegheny-Ludlum
Carbon Steel	U.S. Steel
Galvanized Type C Steel	U.S. Steel
Copperweld Steel	Copperweld Corp.
Polyvinyl Chloride-Coated Steel	Coating Engineering Corp.
Polyethylene-Coated Steel	Republic Steel
VMCH-Coated Steel	Union Carbide Corp.

Table 2

Wire Costs[a]

Wire Cost in Dollars/Pound (Dollars/Kilogram)[b]

Material \ Producer	Allegheny-Ludlum[c] 0.141-in. (3.6-mm) dia. wire	Allegheny-Ludlum[c] 0.160-in. (4.1-mm) dia. wire	Copperweld Corp.[d] 0.141-in. (3.6-mm) dia. wire	Copperweld Corp.[d] 0.160-in. (4.1-mm) dia. wire	Armco Steel 0.141-in. (3.6-mm) dia. wire	Armco Steel 0.160-in. (4.1-mm) dia. wire	U.S. Steel 0.141-in. (3.6-mm) dia. wire	U.S. Steel 0.160-in. (4.1-mm) dia. wire
AISI 201	1.3675 (3.01)	1.2875 (2.84)	—	—	—	—	—	—
AISI 301	1.3675 (3.01)	1.2875 (2.84)	—	—	—	—	1.18 (2.60)	1.15 (2.54)
Armco 18-2	—	—	—	—	1.13 (2.49)	1.19 (2.62)	—	—
AISI 430	1.225 (2.70)	1.095 (2.41)	—	—	1.18 (2.60)	1.05 (2.31)	1.02 (2.25)	0.99 (2.18)
AM 363	1.46 (3.22)	1.38 (3.04)	—	—	—	—	—	—
Copperweld	—	—	0.830 (1.83)	0.824 (1.82)	—	—	—	—
Galvanized Steel	—	—	—	—	—	—	0.2225 (0.49)	0.2225 (0.49)
Carbon Steel	—	—	—	—	—	—	0.1725 (0.38)	0.1725 (0.38)

[a]No cost data are presented for the polyethylene-coated steel because it is no longer produced by Republic Steel or for the polyvinyl chloride-coated steel which is not currently available.

[b]Prices are as of April 1975.

[c]All prices FOB Dunkirk, PA; minimum order 10,000 lb (4536 kg); $0.02 wrapping and packaging.

[d]30,000-lb (13 608 kg) base, plus 5 percent for smaller orders; packaging additional.

Table 3

Typical Chemical Compositions of Stainless Steel Test Specimens

Specimen	Carbon (C)	Chromium (Cr)	Nickel (Ni)	Manganese (Mn)	Phosphorus (P)	Sulfur (S)	Silicon (Si)	Nitrogen (N)	Other
AISI 301	0.15	16.0-18.0	6.0-8.0	2.0	0.045	0.030	1.0	—	
AISI 201	0.15	16.0-18.0	3.5-5.5	5.5-7.5	0.060	0.030	1.0	0.25	
Armco 18-2	0.10	18.0	1.6	12.0	—	—	0.50	0.34	
AISI 430	0.12	15.0-18.0	—	1.0	0.040	0.030	1.0	—	
AM 363	0.04	11.5	4.5	—	—	—	—	—	0.50 Titanium

Table 4

Composition of Revetment Concrete

	Material	Batch Weight, lb (kg)	Percent
I Proportions			
	Portland Cement	139.8 (63.4)	8.35
	Fine Aggregate	558.9 (253.5)	53.38
	Coarse Aggregate	872.4 (395.7)	52.11
	Water	103.1 (46.8)	6.16
	TOTAL	1674.2 (759.4)	100.00
II Mixture Data			
	Ambient Temperature	72°F (22°C)	
	Concrete Temperature	72°F (22°C)	
	Sand/Aggregate Ratio	3.8 Vol %	
	Water/Cement Ratio	0.74 Weight %	
	pH	12	

Table 5

Summary of Exposure Test Parameters

Block Number	Began Exposure	Ended Exposure	Length of Exposure, Months	Specimen Group[a]	Type of Specimens
1	lost in 73 spring flood at Delta Point			A	Straight
2	in storage—New Orleans			A	Straight
3	lost in 73 spring flood at Delta Point			A	Straight
4	in storage—New Orleans			A	Looped
5	in storage—Waterways Experiment Station (WES)			A	Looped
6	in storage—WES			A	Looped
7	May 72	Aug 72	3	A	Straight
8	May 72	May 74	24	A	Straight
9	May 72	Nov 72	6	A	Straight
10	May 72	Aug 72	3	A	Looped
11	May 72	May 75	36	A	Looped
12	May 72	Dec 76	55	A	Looped
13	in storage—CERL			A	Looped
14	lost in 73 spring flood at Delta Point			A	Looped
15	May 73	lost in river, Spring 1976		A	Looped
16	May 73	lost in river, Spring 1976		A	Looped
17	lost in 73 spring flood at Delta Point			A	Looped
18	lost in 73 spring flood at Delta Point			A	Looped
19	May 72	June 72	1	A	Looped
20	May 72	May 73	12	A	Looped

[a]Wire specimens were separated into four groups designated by A, B, C, and D. The materials exposed in each group are listed below in the order of the test blocks:

A. Plain carbon steel, Copperweld, AISI 301, AISI 430, Galvanized, Polyethylene-coated, VMCH-coated, PVC-coated

B. Plain carbon steel, Copperweld, AISI 301, AISI 201, Armco 18-2, AM 363

C. Plain carbon steel, Copperweld, AISI 301, AISI 201, Armco 18-2, AM 363, AISI 430, Galvanized, Polyethylene-coated, PVC-coated

D. Armco 18-2, AISI 301, AISI 201, AM 363, AISI 430; all of these specimens were spot-welded.

Table 5 (cont'd)

Summary of Exposure Test Parameters

Block Number	Began Exposure	Ended Exposure	Length of Exposure, Months	Specimen Group	Type of Specimens
21	May 72	May 74	24	A	Looped
22	May 72	May 73	12	A	Straight
23	May 72	Nov 72	6	A	Straight
24	May 72	June 72	1	A	Straight
25	lost in 73 spring flood at Delta Point			B	Looped
26	lost in 73 spring flood at Delta Point			B	Looped
27	lost in 73 spring flood at Delta Point			B	Looped
28	Nov 72	May 75	30	B	Looped
29	Nov 72	May 74	18	B	Looped
30	Nov 72	Nov 75	36	B	Looped
31	in storage—CERL			B	Looped
32	May 73	Dec 76	43	B	Looped
33	May 73	Dec 76	43	B	Looped
34	lost in 73 spring flood at Delta Point			B	Straight
35	lost in 73 spring flood at Delta Point			B	Straight
36	lost in 73 spring flood at Delta Point			B	Straight
37	Nov 72	May 73	6	B	Straight
38	Nov 72	May 73	6	B	Straight
39	Nov 72	May 74	18	B	Straight
40	in storage—WES			B	Straight
41	in storage—WES			B	Straight
42	in storage—WES			B	Straight
43[b]	Sep 75	Dec 76	15	C	Straight
44	Sep 75	Dec 76	15	C	Straight
45	Sep 75	Dec 76	15	C	Straight
46	Sep 75	Dec 76	15	C	Straight
47	Sep 75	Dec 76	15	C	Straight
48	Sep 75	Dec 76	15	C	Straight
49	in storage—WES			C	Straight
50	in storage—WES			C	Straight
51A	in storage—WES			C	Straight
52A	in storage—WES			C	Straight
W-1	Sep 75	Dec 76	15	D	Straight
W-2	Sep 75	Dec 76	15	D	Straight
W-3	Sep 75	Dec 76	15	D	Straight

[b]Specimens 43 through 48 and W-1 through W-3 were exposed in a brackish water location in the Michoud Canal near New Orleans.

Table 6

Electrical Resistance Data for Wires Exposed in Freshwater[a]

Material	Resistance Before Exposure, mΩ	Resistance After Exposure, mΩ[b] 1 Month	3 Months	6 Months	12 Months	18 Months	24 Months	30 Months	36 Months	43 Months	55 Months
AISI 201	4.40	—	—	4.40	—	4.40	—	4.50	4.49	4.57	—
AISI 301	6.05	6.00	6.00	5.90	5.80	5.95	5.95	6.00	6.23	5.91	5.92
Armco 18-2	14.50	—	—	14.50	—	14.50	—	14.52	15.14	14.6	—
AISI 430	2.85	2.85	2.85	2.70	NA	—	2.80	—	2.97	—	2.83
AM 363	3.00	—	—	2.95	—	2.95	—	3.05	3.00	2.98	—
Carbon Steel	1.60	1.65	1.65	NA	NA	3.30	∞	∞	∞	∞	2.23
Galvanized	2.25	2.54	2.40	2.40	NA	—	2.71	—	2.83	—	2.69
Copperweld	0.66	0.68	0.70	0.70	NA	0.72	0.76	0.72	0.69	0.81	0.86
Polyvinylchloride	7.60	7.10	7.10	7.40	7.30	—	7.30	—	NA	—	—
Polyethylene	1.70	1.75	1.75	—	NA	—	NA	—	1.83	—	—
VMCH	—	1.62	1.60	—	NA	—	NA	—	1.46	—	—

[a]Resistance was measured along a 4.0-in. (101.6-mm) length with the concrete-water interface generally located at the midpoint.

[b]NA indicates a specimen for which resistance data were not obtained; — indicates that there was no specimen for that combination of material and length of exposure.

Table 7

Electrical Resistance Data for Wires Exposed in Brackish Water

Material	Resistance Before Exposure, mΩ	Resistance After 15 Months of Exposure, mΩ	
		Block 45	Block 48
AISI 201	4.40	4.61	4.34
AISI 301	6.05	6.03	6.09
Armco 18-2	14.50	15.35	14.85
AISI 430	2.85	3.18	2.97
AM 363	3.00	3.09	3.07
Carbon Steel	1.60	2.15	2.05
Galvanized	2.25	2.70	2.78
Copperweld	0.66	0.77	0.75

Table 8

Tensile Test Data—AISI 201 Stainless Steel Wire[a]

	Specimen	Maximum Load, lbf (N)	Tensile Strength, ksi (MPa)	Reduction in Area, percent	R_t[b]	Failure Location	ϵ_f[c]
I Unexposed Standard	1	4525 (20127)	178 (1227)	34	—	—	0.42
	2	4550 (20238)	179 (1234)	33	—	—	0.40
	3	4600 (20461)	181 (1248)	37	—	—	0.46
	4	4600 (20461)	181 (1248)	38	—	—	0.48
	Average	4569 (20323)	180 (1241)	35.5	—	—	0.44
II Freshwater Exposure							
6 months (Block 38)		4475 (19905)	176 (1213)	33.3	0.98	water	0.40
18 months (Block 39)		4570 (20327)	180 (1241)	37.6	1.00	water	0.47
30 months (Block 28)		4400 (19571)	176 (1213)	NA	0.96	NA	NA
36 months (Block 30)		4460 (19838)	178 (1227)	59	0.98	water	0.89
43 months (Block 32)		4500 (20016)	180 (1241)	38.3	0.98	water	0.48
III Brackish Water Exposures							
15 months (Block 15)		4500 (20016)	180 (1241)	38.9	0.98	water	0.49

[a] 0.180-in. (4.58-mm) diameter, 0.025-sq in. (16.4-mm²) cross section.

[b] Ratio of strength of exposed specimens to average strength of unexposed standards.

[c] True strain of fracture.

Table 9

Tensile Test Data—AISI 301 Stainless Steel Wire[a]

	Specimen	Maximum Load lbf (N)	Tensile Strength, ksi (MPa)	Reduction in Area, percent	R,[b]	Failure Location	ϵ_f[c]
I Unexposed Standard	1	4180 (18593)	200 (1379)	36	—	—	0.45
	2	4120 (18326)	197 (1358)	36	—	—	0.45
	3	4075 (18126)	195 (1344)	34	—	—	0.42
	4	4075 (18126)	195 (1344)	37	—	—	0.46
	Average	4112 (18290)	197 (1358)	35.7	—	—	0.44
II Freshwater Exposures							
1 month (Block 30)		4000 (17792)	192 (1324)	35.6	0.97	water	0.44
3 months (Block 7)		3900 (17347)	187 (1289)	36.2	0.95	water	0.45
6 months (Block 9)		3900 (17347)	187 (1289)	36.2	0.95	water	0.45
6 months (Block 38)		4200 (18682)	201 (1386)	19.6	1.02	water	0.22
12 months (Block 22)		4175 (18570)	200 (1379)	35.0	1.02	concrete	0.43
18 months (Block 39)		4160 (18504)	199 (1372)	34.8	1.01	concrete	0.43
24 months (Block 8)		4050 (18014)	194 (1338)	37.7	0.98	concrete/water interface	0.47
30 months (Block 28)		4250 (18904)	202 (1393)	NA	1.03	NA	NA
36 months (Block 11)		4100 (18237)	195 (1344)	NA	1.00	NA	NA
43 months (Block 32)		4034 (17943)	192 (1324)	39.9	0.98	water	0.51
55 months (Block 12)		4167 (18535)	198 (1365)	38.0	1.01	concrete	0.48
15 months (Block 45)		4070 (18103)	194 (1337)	38.0	0.99	concrete	0.48

[a] 0.163-in. (4.14-mm) diameter, 0.021-sq in. (13.4-mm²) cross section.
[b] Ratio of strength of exposed specimens to average strength of unexposed standards.
[c] True strain at fracture.

Table 10

Tensile Test Data—Armco 18-2 Stainless Steel Wire[a]

	Specimen	Maximum Load, lbf (N)	Tensile Strength, ksi (MPa)	Reduction in Area, percent	R,[b]	Failure Location	ϵ_f[c]
I Unexposed Standard	1	2090 (9296)	265 (1827)	0	—	—	0
	2	2425 (10786)	309 (2130)	0	—	—	0
	3	2360 (10497)	300 (2068)	0	—	—	0
	4	2350 (10453)	299 (2062)	0	—	—	0
	Average	2306 (10257)	293 (2020)	0	—	—	0
II Freshwater Exposures							
6 months (Block 38)		2400 (10675)	306 (2110)	0	1.04	concrete	0
18 months (Block 39)		2350 (10453)	299 (2062)	0	1.02	water	0
30 months (Block 28)		2400 (10676)	306 (2110)	NA	1.04	NA	NA
36 months (Block 30)		2300 (10230)	288 (1986)	0	1.00	water	0
43 months (Block 32)		2203 (9799)	275 (1899)	1.0	0.96	concrete	0.01
III Brackish Water Exposure							
15 months (Block 45)		1200 (5338)	150 (1034)	0	0.52	water	0

[a] 0.100-in. (2.45-mm) diameter, 0.008-sq in. (5.1-mm²) cross section.
[b] Ratio of strength of exposed specimens to average strength of unexposed standards.
[c] True strain at fracture.

Table 11

Tensile Test Data—AISI 430 Stainless Steel Wire[a]

	Specimen	Maximum Load, lbf (N)	Tensile Strength, ksi (MPa)	Reduction in Area, percent	R_t[b]	Failure Location	ϵ_f[c]
I Unexposed Standard	1	4300 (19126)	137 (945)	32	—	—	0.39
	2	4360 (19393)	139 (958)	32	—	—	0.39
	3	4370 (19438)	139 (958)	30	—	—	0.36
	4	4420 (19660)	141 (972)	31	—	—	0.39
	Average	4362 (19402)	139 (958)	31.2	—	—	0.39
II Freshwater Exposures							
1 month (Block 19)		4100 (18237)	131 (903)	29.5	0.94	—	0.35
3 months (Block 7)		4200 (18632)	134 (924)	25.0	0.96	water	0.29
6 months (Block 9)		4250 (18904)	135 (931)	30.3	0.97	water	0.36
12 months (Block 22)		4275 (19015)	136 (938)	31.5	0.98	concrete/water interface	0.38
24 months (Block 8)		4180 (18593)	133 (917)	28.9	0.96	concrete/water interface	0.34
36 months (Block 11)		4275 (19015)	136 (938)	NA	0.98	NA	NA
55 months (Block 12)		4133 (18384)	130 (896)	34.5	0.98	concrete	0.42
III Brackish Water Exposures							
15 months (Block 45)		2690 (11965)	87 (598)	2.0	0.62	water	0.02

[a]0.200-in. (5.08-mm) diameter, 0.031-sq in. (20.3-mm²) cross section.
[b]Ratio of strength of exposed specimens to average strength of unexposed standards.
[c]True strain at fracture.

Table 12

Tensile Test Data—AM 363 Stainless Steel Wire[a]

	Specimen	Maximum Load, lbf (N)	Tensile Strength, ksi (MPa)	Reduction in Area, percent	R_t[b]	Failure Location	ϵ_f[c]
I Unexposed Standard	1	4600 (20461)	124 (855)	49.3	—	—	0.68
	2	4600 (20461)	124 (855)	51.6	—	—	0.73
	3	4600 (20461)	124 (855)	48.8	—	—	0.67
	4	4600 (20461)	124 (855)	49.8	—	—	0.69
	Average	4600 (20461)	124 (855)	49.8	—	—	0.69
II Freshwater Exposures							
6 months (Block 33)		4575 (20350)	124 (855)	45.2	0.99	concrete	0.60
18 months (Block 39)		4520 (20105)	122 (841)	49.3	0.98	concrete/water interface	0.68
30 months (Block 28)		4575 (20350)	124 (855)	NA	0.99	NA	NA
36 months (Block 30)		4320 (19215)	117 (807)	74	0.94	water	1.35
43 months (Block 32)		4210 (18726)	114 (786)	57.1	0.92	concrete	0.85
III Brackish Water Exposures							
15 months (Block 45)		3933 (17494)	106 (731)	38.7	0.86	water	0.49

[a]0.217-in. (5.51-mm) diameter, 0.037-sq in. (23.8-mm²) cross section.
[b]Ratio of strength of exposed specimens to average strength of unexposed standards.
[c]True strain at fracture.

Table 13

Tensile Test Data—Carbon Steel Wire[a]

		Specimen	Maximum Load, lbf (N)	Tensile Strength, ksi (MPa)	Reduction in Area, percent	R_t[b]	Failure Location	ϵ_f[c]
I Unexposed Standard		1	4225 (18793)	205 (1413)	23.5	—	—	0.27
		2	4180 (18593)	203 (1400)	18.5	—	—	0.20
		3	4225 (18793)	205 (1413)	19.0	—	—	0.21
		4	4175 (18570)	203 (1400)	19.0	—	—	0.21
		Average	4201 (18686)	204 (1407)	20.0	—	—	0.22
II Freshwater Exposures								
1 month	(Block 19)		3950 (17570)	192 (1324)	19.8	0.94	concrete/water interface	0.22
3 months	(Block 7)		3350 (14901)	168 (1158)	26.5	0.80	concrete/water interface	0.31
6 months	(Block 9)		3450 (15346)	167 (1151)	26.5	0.82	water	0.31
	(Block 38)		3050 (13566)	148 (1020)	29.6	0.73	water	0.35
12 months	(Block 20)		2675 (11898)	130 (896)	35.2	0.64	concrete/water interface	0.43
18 months	(Block 39)		1580 (7028)	77 (531)	51.2	0.38	concrete/water interface	0.72
24 months	(Block 8)[d]		0 (0)	0 (0)	—	0	—	—
30 months	(Block 28)[d]		0 (0)	0 (0)	—	0	—	—
36 months	(Block 11)[d]		0 (0)	0 (0)	—	0	—	—

[a]0.162-in. (4.11-mm) diameter, 0.021-sq in. (13.3-mm²) cross section.
[b]Ratio of strength of exposed specimens to average strength of unexposed standards.
[c]True strain at fracture.
[d]Completely corroded into two pieces.

Table 14

Tensile Test Data—Galvanized Carbon Steel Wire[a]

		Specimen	Maximum Load, lbf (N)	Tensile Strength, ksi (MPa)	Reduction in Area, percent	R_t[b]	Failure Location	ϵ_f[c]
I Unexposed Standard		1	1790 (7961)	158 (1089)	18.3	—	—	0.20
		2	1800 (8006)	159 (1096)	18.8	—	—	0.21
		3	1810 (8051)	160 (1103)	17.5	—	—	0.19
		Average	1800 (8006)	159 (1096)	18.2	—	—	0.20
II Freshwater Exposures								
1 month	(Block 19)		1800 (8006)	159 (1096)	25.0	1.00	concrete/water interface	0.29
3 months	(Block 7)		1800 (8006)	159 (1096)	22.5	1.00	concrete/water interface	0.25
6 months	(Block 9)		1800 (8006)	159 (1096)	6.7	1.00	concrete/water interface	0.07
12 months	(Block 22)		1800 (8006)	159 (1096)	24.2	1.00	concrete/water interface	0.28
24 months	(Block 8)		1830 (8140)	162 (1117)	21.5	1.02	concrete/water interface	0.24
36 months	(Block 11)		1775 (7895)	161 (1110)	NA	0.99	NA	NA
55 months	(Block 12)		1434 (6378)	130 (899)	29.2	0.80	water	0.34
III Brackish Water Exposures								
15 months	(Block 45)[d]		5033 (22387)	240 (1652)	39.8	—	water	0.49

[a]0.120-in. (3.05-mm) diameter, 0.011-sq in. (7.3-mm²) cross section.
[b]Ratio of strength of exposed specimens to average strength of unexposed standards.
[c]True strain at fracture.
[d]0.166-in. (4.22-mm) diameter, 0.022-sq in. (14.0-mm²) cross section.

Table 15

Tensile Test Data—Copperweld Carbon Steel Wire[a]

	Specimen	Maximum Load, lbf (N)	Tensile Strength, ksi (MPa)	Reduction in Area, percent	R_t[b]	Failure Location	ϵ_f[c]
I Unexposed Standard	1	1440 (6405)	108 (745)	27.9	—	—	0.32
	2	1440 (6405)	108 (745)	28.7	—	—	0.34
	3	1440 (6405)	108 (745)	27.1	—	—	0.32
	4	1430 (6361)	108 (745)	26.4	—	—	0.31
	Average	1438 (6396)	108 (745)	27.5	—	—	0.32
II Freshwater Exposure							
1 month	(Block 19)	1350 (6005)	104 (717)	30.0	0.94	concrete/water interface	0.36
3 months	(Block 7)	1400 (6405)	105 (724)	29.2	0.97	water	0.35
6 months	(Block 9)	1450 (6450)	108 (745)	30.8	1.01	concrete	0.37
6 months	(Block 38)	1400 (6405)	105 (724)	33.1	0.97	water	0.40
12 months	(Block 22)	1225 (5449)	92 (634)	32.3	0.85	concrete	0.39
18 months	(Block 39)	1400 (6405)	105 (724)	25.6	0.97	concrete	0.30
24 months	(Block 8)	1410 (6272)	105 (724)	27.9	0.98	water	0.32
30 months	(Block 28)	1350 (6005)	104 (717)	NA	0.94	NA	NA
36 months	(Block 11)	1350 (6005)	104 (717)	NA	0.94	NA	NA
36 months	(Block 30)	1350 (6005)	104 (717)	44.0	0.94	water	0.58
43 months	(Block 32)	1270 (5649)	98 (674)	28.5	0.88	water	0.34
55 months	(Block 12)	1250 (5560)	96 (663)	32.3	0.87	water	0.39
III Brackish Water Exposures							
15 months	(Block 45)	1366 (6076)	105 (724)	28.5	0.95	water	0.34

[a] 0.130-in. (3.30-mm) diameter, 0.013-sq in. (8.6-mm^2) cross section.
[b] Ratio of strength of exposed wired to average strength of unexposed standards.
[c] True strain at fracture.

Table 16

Tensile Test Data—PVC-Coated Carbon Steel Wire[a]

	Specimen	Maximum Load, lbf (N)	Tensile Strength, ksi (MPa)	Reduction in Area, percent	R_t[b]	Failure Location	ϵ_f[c]
I Unexposed Standard	1	340 (1512)	77 (531)	34.7	—	—	0.43
	2	310 (1379)	70 (483)	45.3	—	—	0.60
	3	340 (1512)	77 (531)	52.0	—	—	0.73
	4	343 (1526)	78 (538)	49.3	—	—	0.68
	Average	333 (1481)	75.5 (521)	45.3	—	—	0.60
II Freshwater Exposures							
1 month	(Block 19)	300 (1334)	68 (469)	37.3	0.90	concrete	0.47
3 months	(Block 7)	325 (1446)	74 (510)	26.7	0.98	concrete/water interface	0.31
6 months	(Block 9)	350 (1557)	79 (545)	49.3	1.05	concrete	0.68
12 months	(Block 22)	350 (1557)	79 (545)	48.0	1.05	water	0.65
24 months	(Block 8)	313 (1392)	71 (490)	51.6	0.94	water	0.73
36 months	(Block 11)	350 (1557)	87.5 (600)	NA	1.05	NA	NA

[a] 0.075-in. (1.90-mm) diameter, 0.004-sq in. (2.8-mm^2) cross section.
[b] Ratio of strength of exposed specimens to average strength of unexposed standards.
[c] True strain at fracture.

Table 17

Tensile Test Data—Polyethylene Coated Carbon Steel Wire[a]

	Specimen	Maximum Load, lbf (N)	Tensile Strength, ksi (MPa)	Reduction in Area, percent	R_r[b]	Failure Location	ϵ_f[c]
I Unexposed Standard	1	4270 (18993)	210 (1448)	24.8	—	—	0.29
	2	4270 (18993)	210 (1448)	22.5	—	—	0.25
	3	4250 (18904)	209 (1441)	36.0	—	—	0.45
	4	4250 (18904)	209 (1441)	24.2	—	—	0.28
	Average	4260 (18948)	209.5 (1444)	27.2	—	—	0.32
II Freshwater Exposures							
1 month	(Block 19)	4200 (18682)	206 (1420)	29.8	0.99	water	0.26
3 months	(Block 7)	4250 (18904)	209 (1441)	29.2	1.00	water	0.35
6 months	(Block 9)	4300 (19126)	211 (1455)	28.0	1.01	concrete/water interface	0.33
12 months	(Block 22)	4050 (18014)	200 (1379)	29.2	0.95	concrete/water interface	0.35
24 months	(Block 8)	4250 (18904)	209 (1441)	28.6	1.00	water	0.34
36 months	(Block 11)	4370 (19438)	219 (1510)	NA	1.03	NA	NA

[a] 0.161-in. (4.09-mm) diameter, 0.020-sq in. (13.1-mm²) cross section.
[b] Ratio of strength of exposed specimens to average strength of unexposed standards.
[c] True strain at fracture.

Table 18

Depth of Corrosion in Copperweld Steel Wires[a]

Block	Exposure Time, months	Depth of Corrosion, in. (mm)
I Freshwater Exposure		
19	1	0.047 (1.19)
7	3	0.087 (2.21)
10	3	0.079 (2.01)
9	6	0.224 (5.69)
23	6	0.205 (5.21)
37	6	0.264 (6.71)
38	6	0.256 (6.50)
20	12	0.374 (9.50)
22	12	0.236 (5.99)
29	18	0.512 (13.00)
39	18	0.433 (11.00)
8	24	0.433 (11.00)
21	24	0.433 (11.00)
30	36	0.375 (9.53)
32	43	0.625 (15.88)
33	43	0.500 (12.7)
12	55	0.625 (15.88)
II Brackish Water Exposure		
45	15	0.875 (22.22)
48	15	1.00 (25.40)

[a] All penetration depths were measured on the ends submerged in water.

Table 19

Average Corrosion Rates of Various Stainless Steels Determined by 65 Percent Boiling Nitric Acid Test

		Welding Conditions			
Alloy	**State**[a]	**Electrode Loading, lbf (N)**	**Secondary Amps**	**Cycles**	**Corrosion Rate, mpg (mm/yr)**
Armco 18-2	AR(1)	—	—	—	42.5 (1.08)
	W(1)	390 (1735)	7000	1	44.3 (1.13)
	AR(2)	—	—	—	29.4 (0.75)
	W(2)	390 (1735)	3000	2	49.1 (1.25)
	AR(3)	—	—	—	39.7 (1.01)
	W(3)	300 (1334)	3500	3	ND ND
	S	—	—	—	97.7 (2.48)
AISI 301	AR(1)	—	—	—	21.7 (0.55)
	W(1)	600 (2668)	3000	4	22.9 (0.58)
	AR(2)	—	—	—	18.0 (0.46)
	W(2)	780 (3469)	7000	5	23.2 (0.59)
	AR(3)	—	—	—	19.9 (0.51)
	W(3)	780 (3469)	3500	5	22.7 (0.58)
	S	—	—	—	49.5 (1.26)
AISI 201	AR(1)	—	—	—	44.3 (1.25)
	W(1)	800 (3558)	14000	4	57.5 (1.46)
	AR(2)	—	—	—	46.0 (1.17)
	W(2)	1170 (5204)	17500	5	47.1 (1.20)
	AR(3)	—	—	—	43.8 (1.11)
	W(3)	980 (4359)	14000	7	54.4 (1.38)
	S	—	—	—	49.0 (1.24)
AISI 430	AR(1)	—	—	—	48.0 (1.22)
	W(1)	800 (3558)	14000	4	47.4 (1.20)
	AR(2)	—	—	—	48.5 (1.23)
	W(2)	1170 (5204)	10500	7	49.3 (1.25)
	AR(3)	—	—	—	46.8 (1.19)
	W(3)	960 (4270)	14000	7	58.1 (1.48)
	S	—	—	—	71.4 (1.81)
AM 363	AR(1)	—	—	—	297.5 (7.56)
	W(1)	960 (4270)	3500	5	326.9 (8.30)
	AR(2)	—	—	—	ND ND
	W(2)	960 (4270)	10500	7	320.2 (8.13)
	AR(3)	—	—	—	332.7 (8.45)
	W(3)	1170 (5205)	10500	7	326.9 (8.30)
	S	—	—	—	230.0 (5.84)

[a] AR = as-received, two samples
W = welded, one sample
S = sensitized, four samples
ND = no data—condenser broke

Table 20

Typical Tap Water Analysis (Treated)

Chemical	Quantity, mg/l	
Iron	0.0	
Manganese	0.0	
Calcium	35.0	
Magnesium	45.0	
Ammonium	0.0 to 2.0	
Sodium	35.0	
Silica	7.0	
Fluoride	1.0	
Chloride	4.0	
Sulfate	35.0	
Nitrate	0.4	
P. Alkalinity	14.0	
T. Alkalinity	115.0	
Hardness	80.0	
Total Dissolved Mineral	160.0	
Turbidity		0.0 units
Color		0.0 units
Odor		0.0 units
pH		9.0

Table 21

Open Circuit Corrosion Rates of Stainless Steels in Tap Water

Material	Corrosion Rate mpy (mm/yr $\times 10^{-3}$)
AISI 201	0.008 (0.203)
AISI 301	0.030 (0.762)
AM 363	0.001 (0.025)
Armco 18-2	0.008 (0.203)
AISI 430	0.007 (0.178)

Table 22

Uncoupled Open Circuit Potentials and Corrosion Rates of Low Carbon Steel, Copper, and Zinc in Tap Water

Material	Potential, V (SCE)	Corrosion Rate, mpy (mm/yr)
Low-Carbon Steel	−0.645	5.4 (0.137)
Copper	+0.007	0.073 (0.019)
Zinc	−1.017	0.34 (0.009)

Table 23

Candidate Materials for Mississippi River Revetments

Trade Name	Type[a]	Percent Chromium	Percent Nickel	Tensile Strength,[b] ksi	(MPa)
AISI 405	F	11-15	0	90	(621)
Armco 400	F	12.5	0	60	(414)
Armco 409	F	11.5	0	70	(483)
Armco 18 SR	F	18	0	93	(641)
Carpenter No. 1-Jr	F	13	0	86	(593)
Carpenter SF	F	14	0.5	90	(621)
Carpenter 434 Hs	F	17	0	80-140	(552-965)
Croloy 16-1	F	15	1.25	90	(621)
Crucible 430 T	F	17.5	0	70	(483)
Crucible Bright E3	F	12	0.5	70	(483)
Crucible EZ	F	11	0	70	(483)
Crucible EZ-Mod.	F	12	0	80	(552)
Crucible E3-NT	F	13	0	70	(483)
Crucible E4	F	11.5	0	80	(552)
Glass Sealing 18	F	18	0.2	80	(552)
HWT	F	18	0.5	70	(483)
J&L 20-Mo	F	20	0	80	(552)
Project 70	F	18	0	70	(483)
Republic 444L	F	18.5	0	85	(586)
MF-2	F	12	0.5	70	(483)
OR-1	F	12.5	0.5	75	(517)
Unilec 1409L	F	13	0	95	(656)
Uniseal 18	F	19	0.2	70	(483)
Armco 22-4-9	A	21	3.5	160	(1103)
Croloy 299	A	17	1.5	170	(1172)
Crucible 16-16-1	A	16	1.0	105	(724)
Crucible 223	A	16	0.6	110	(758)
Nitronic 32[c]	A	18	1.5	120	(827)
Nitronic 33	A	18	3.3	115	(793)
Tenelon	A	18	0	125	(862)
205	A	17	1.3	125	(862)

[a]F = ferritic stainless steel, A = austenitic stainless steel.
[b]Handbook values for tensile strength; can be greatly elevated by coldwork.
[c]Same as Armco 18-2.

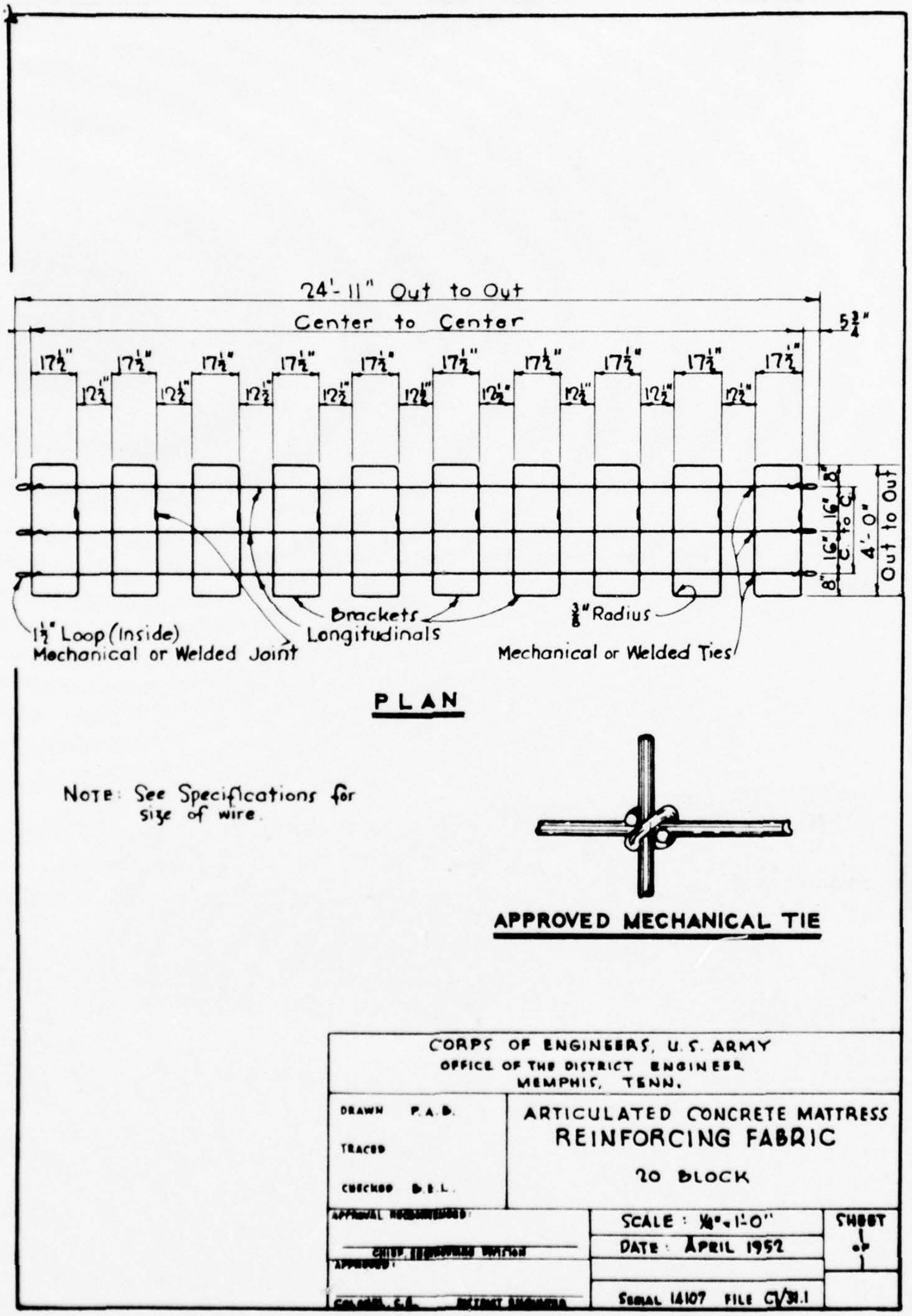


Figure 1. Articulated concrete mattress reinforcing fabric.
SI conversion factor: 1 in. = 25.4 mm.

Figure 2. "Squares" after casting. The squares consist of concrete slabs cast onto the wire fabric.

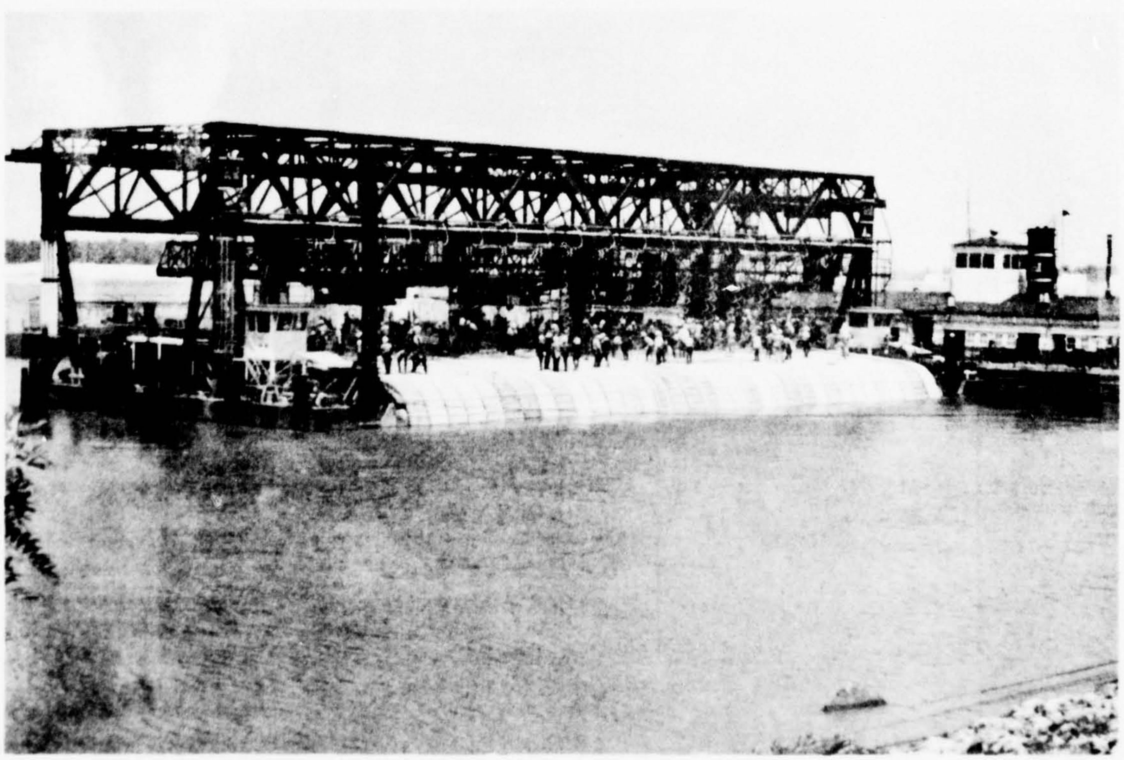


Figure 3. Articulated concrete mattress (after assembly) being launched.

Figure 4. Test block with looped-end test wires after exposure.

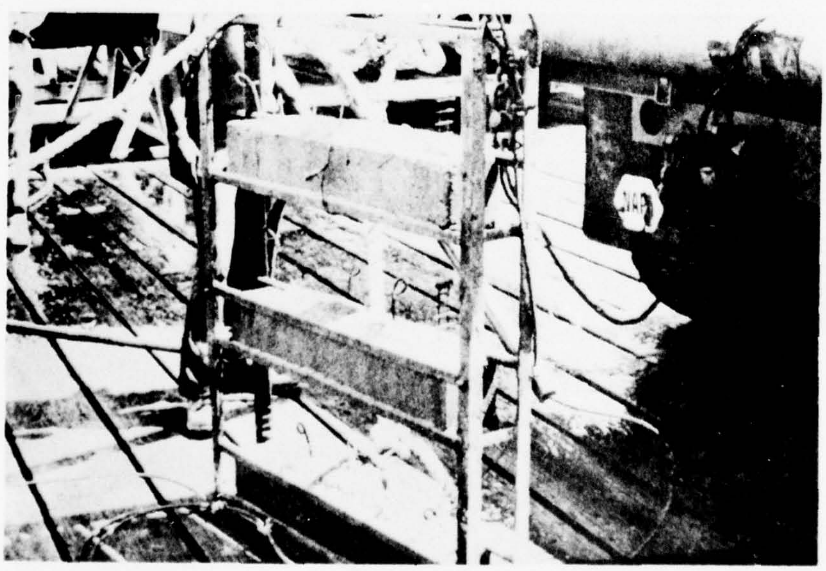


Figure 5. Exposure rack. Specimen blocks were inserted into the horizontal shelves, and the entire assembly was lowered into the Mississippi River or Michoud Canal environment.

Figure 6. Spot-welded stainless steel wire specimens exposed 15 months in brackish water. From left: AM 363, AISI 201, Armco 18-2, AISI 430, and AISI 301. (Block W-2)

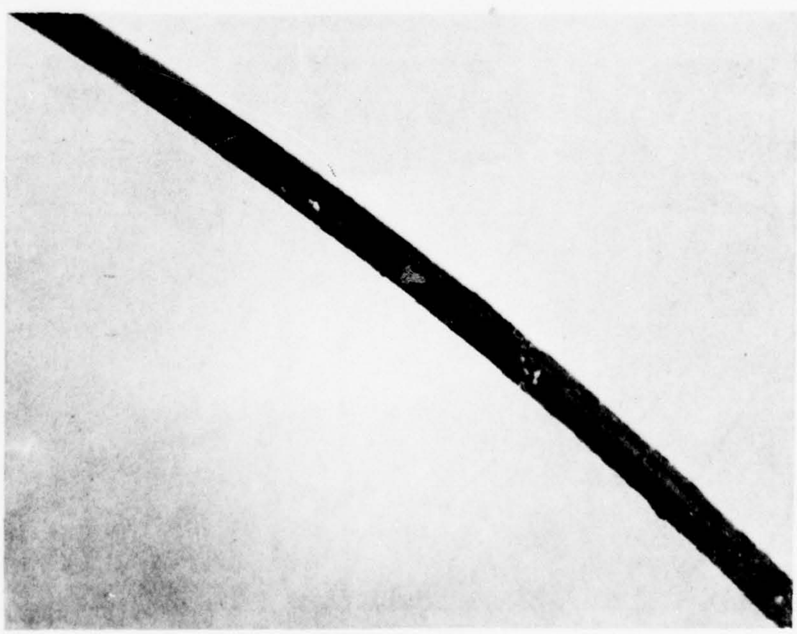


Figure 7. Corrosion and pitting in AISI 430 stainless steel. (Block 45)

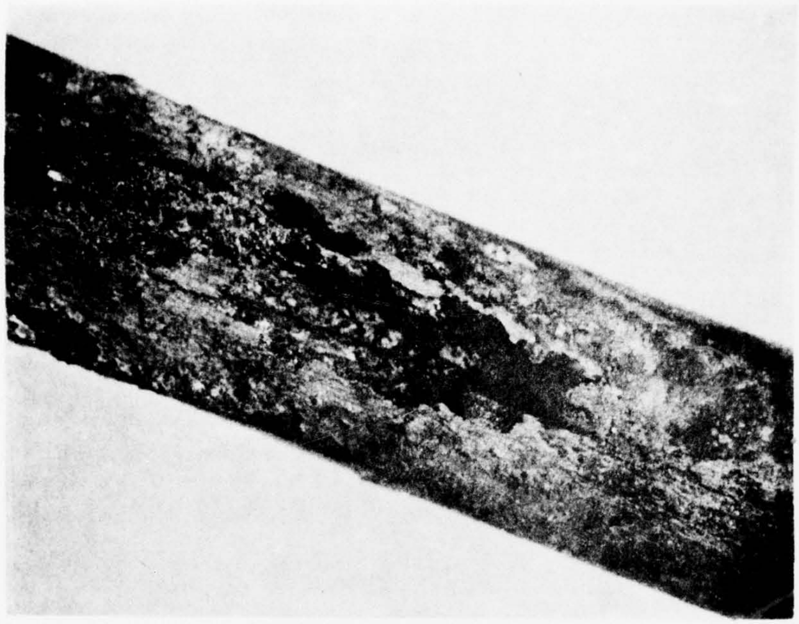
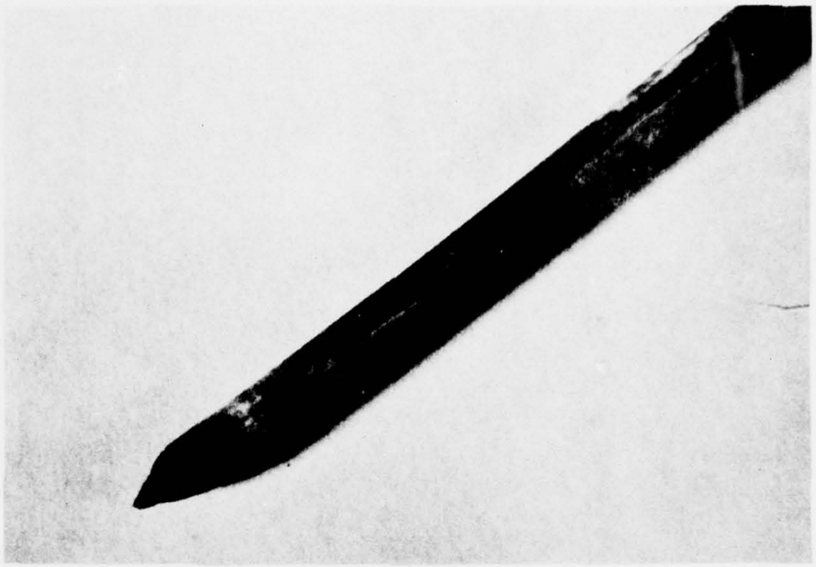


Figure 8. Corrosion attack into the interior of an AISI 430 stainless steel specimen. Only a thin uncorroded outer layer remains. (Block 45) (7.5x)

Figure 9. Corrosion and pitting in AM 363 stainless steel wire after 15 months of exposure in brackish water. (Block 48)



a. Freshwater specimen.

b. Brackish water specimen.

Figure 10. Accelerated corrosion in plain carbon steel wire at the region where the wire exits from the concrete.

Figure 11. SEM photograph of the accelerated corrosion region in plain carbon steel wire. Note the geometry of attack, the layered corrosion region, and the apparent attack at the grain boundaries.

Figure 12. Micrograph of galvanized wire after exposure for 1 year. Note the presence of deep pits in the zinc outer layer which penetrate to the surface of the steel. (50x)

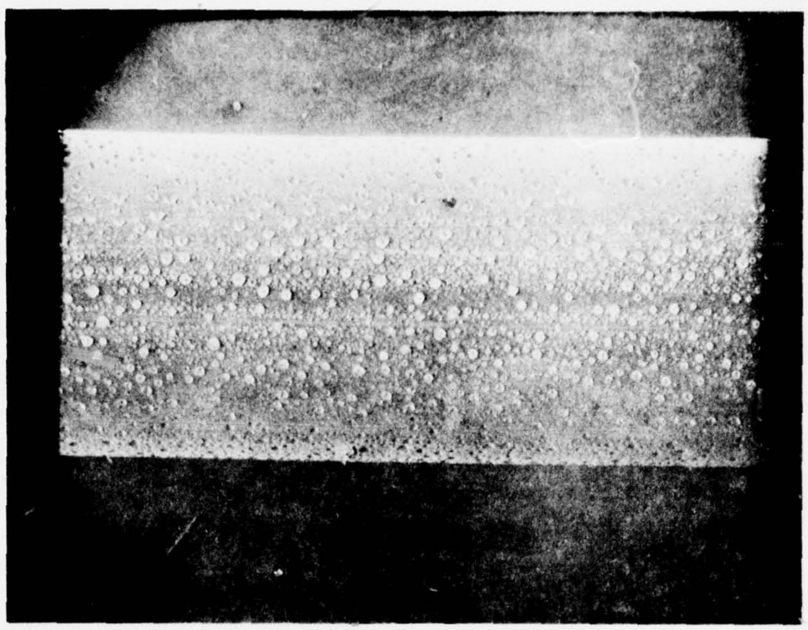


Figure 13. SEM micrograph of unexposed galvanized wire surface. This shows that the zinc outer layer is pitted prior to exposure.

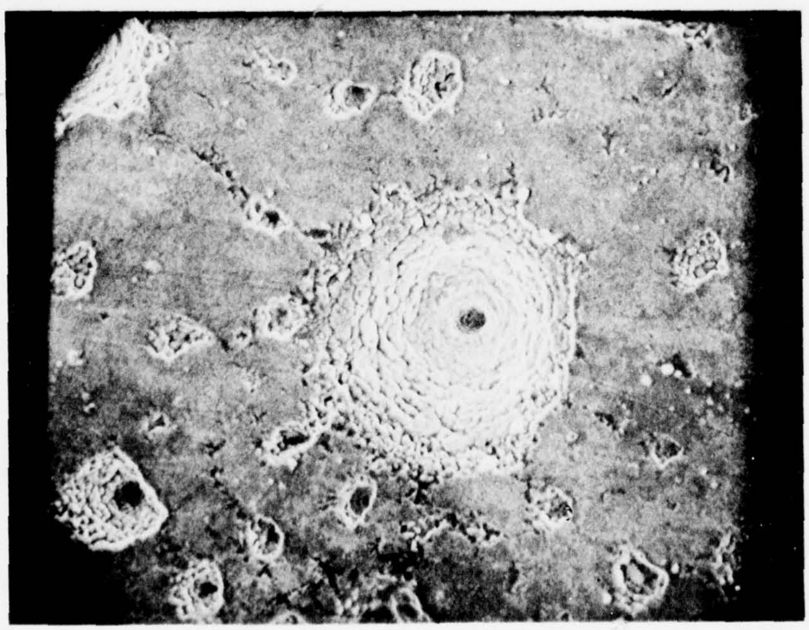


Figure 14. High-magnification SEM micrograph of pits (pores) in the zinc surface. (500x)

. **Figure 15.** Exposed end of copper-clad steel wire after exposure. Note the porous steel core and the attack on the insiae of the copper cladding. (55x)

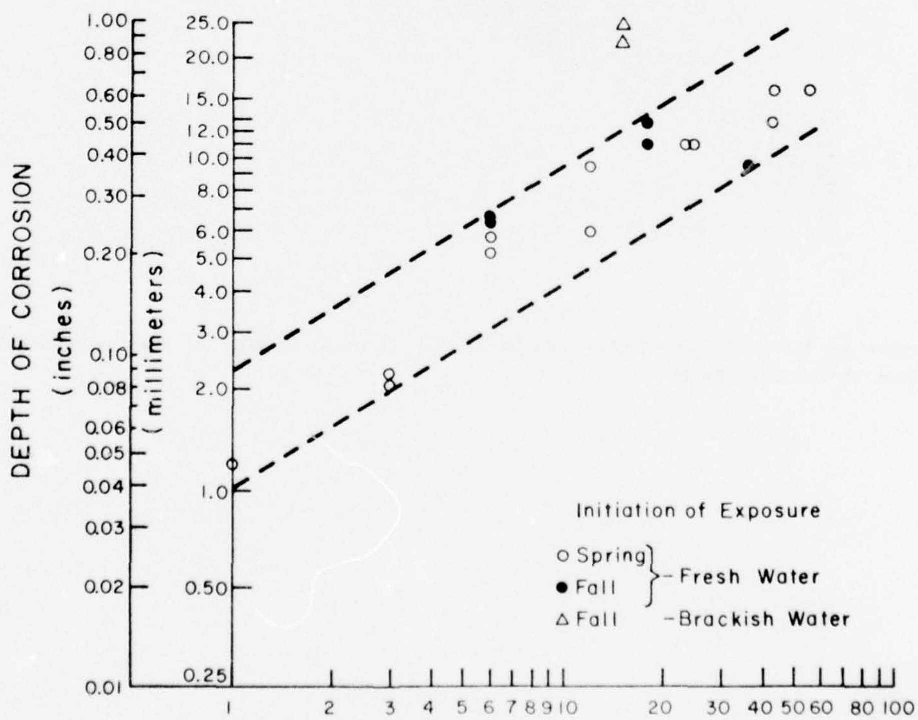


Figure 16. Depth of corrosion into the exposed end of copper-clad steel wires.

Figure 17. Localized corrosion attack in the copper cladding after 15 months exposure in brackish water. (Block 48)

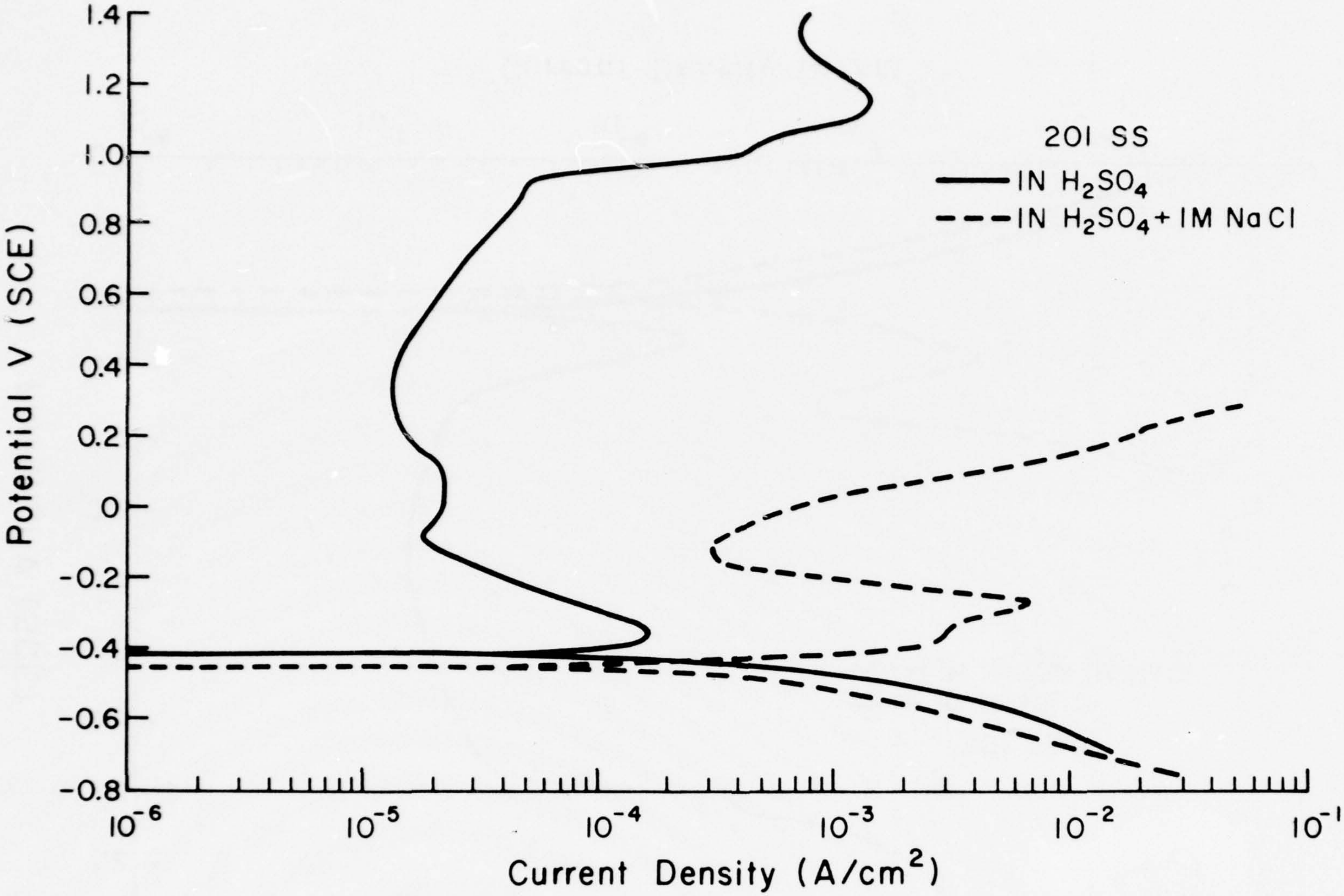


Figure 18. Potentiodynamic polarization curves for AISI 201 stainless steel.

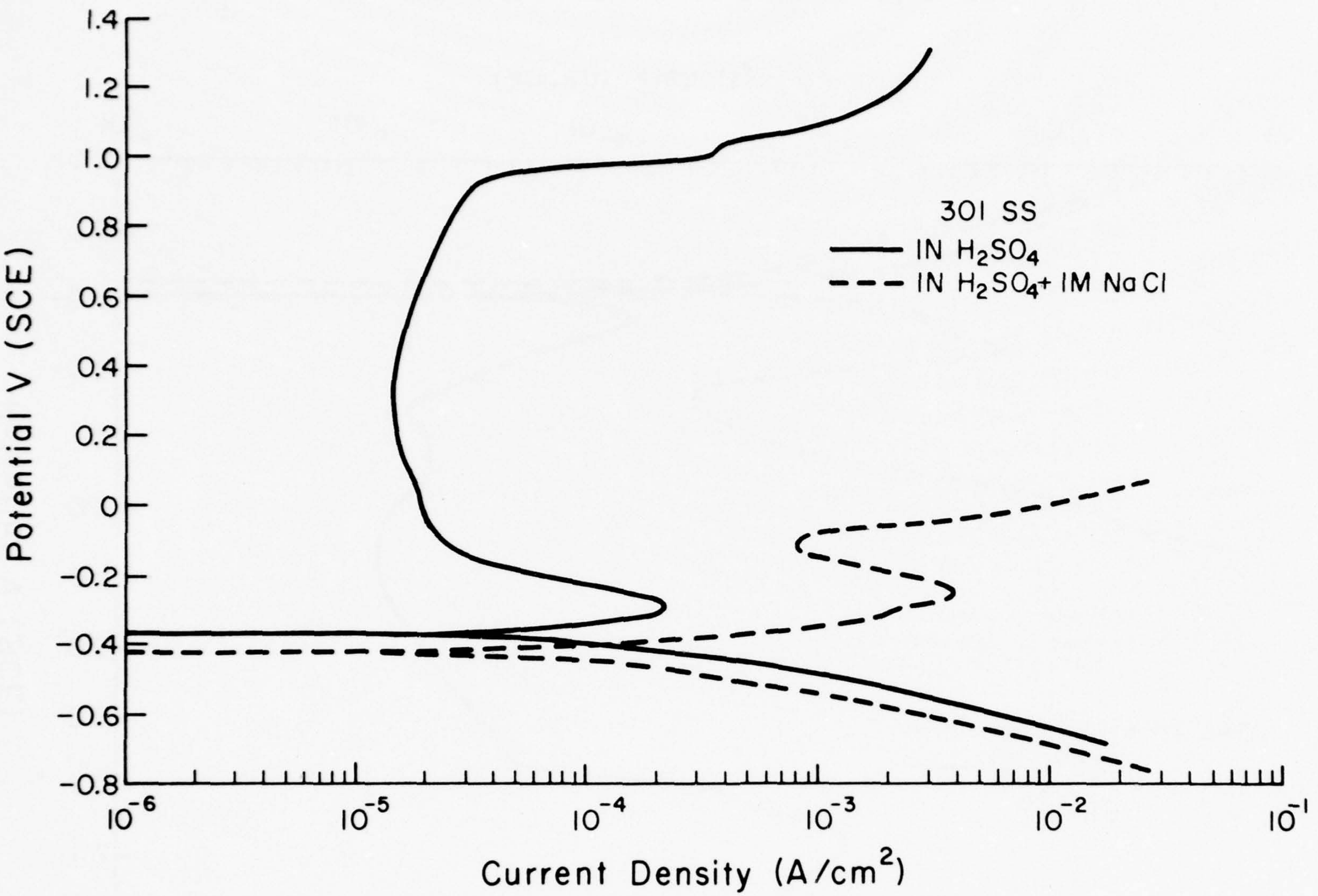


Figure 19. Potentiodynamic polarization curves for AISI 301 stainless steel.

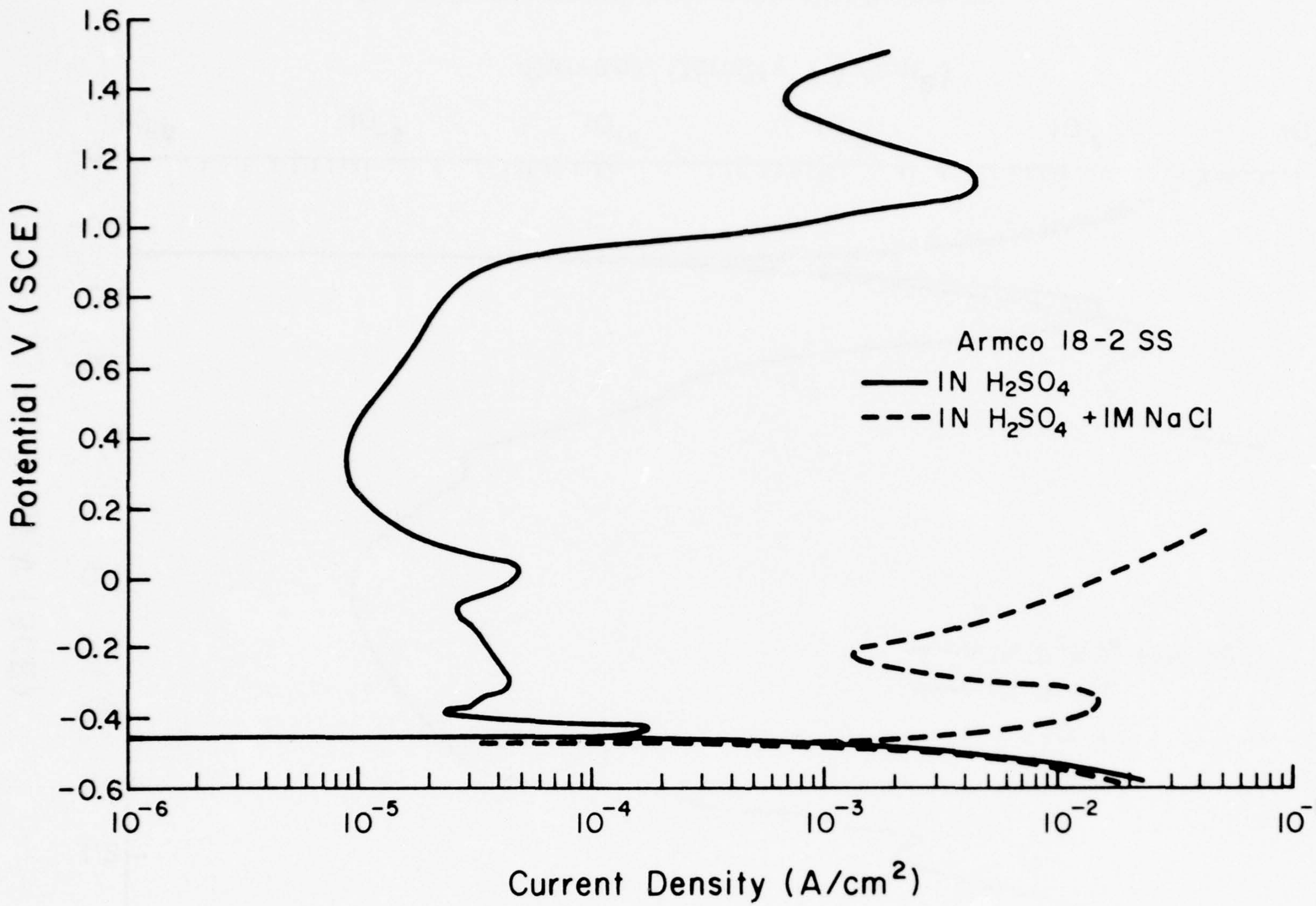


Figure 20. Potentiodynamic polarization curves for Armco 18-2 stainless steel.

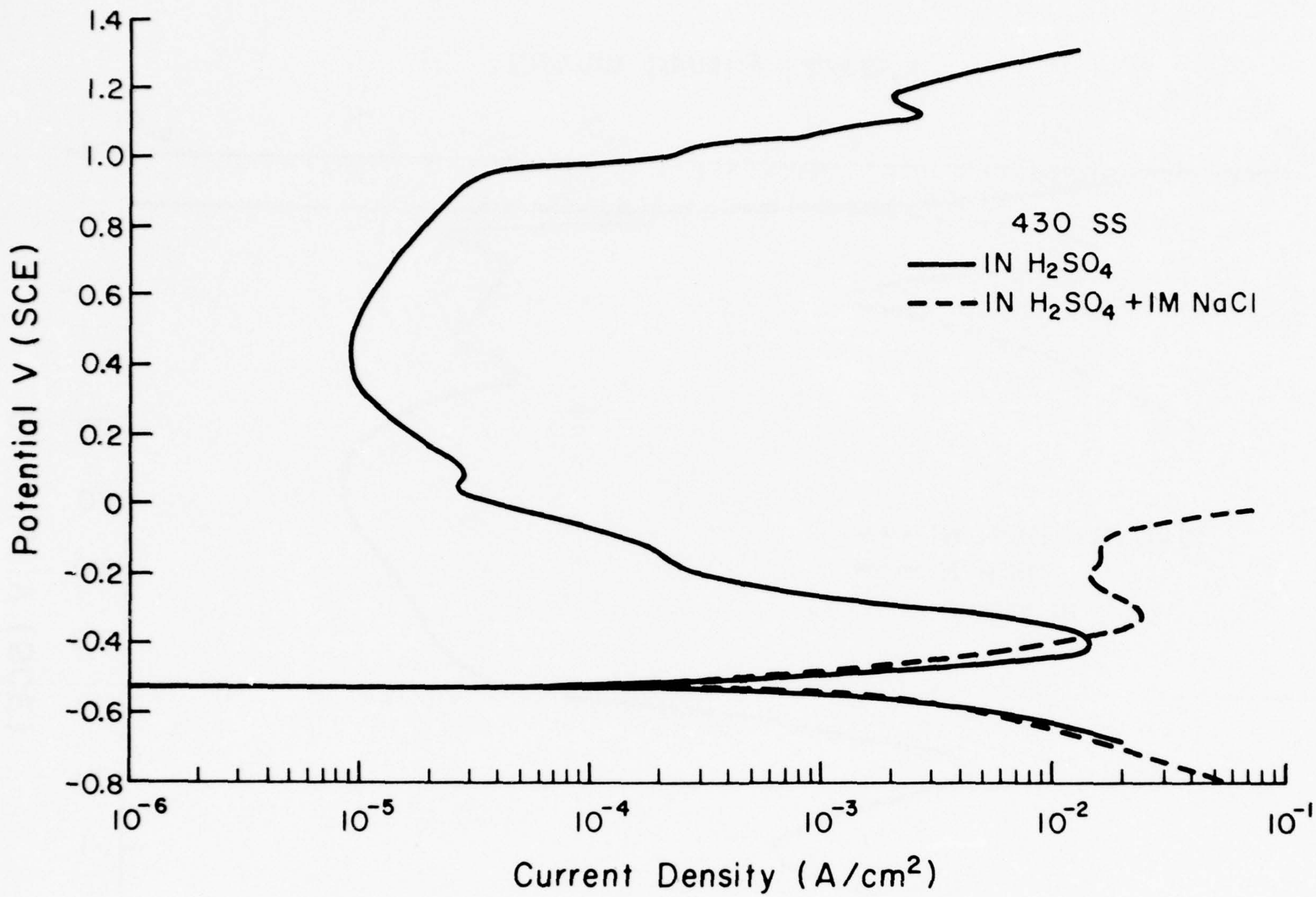


Figure 21. Potentiodynamic polarization curves for AISI 430 stainless steel.

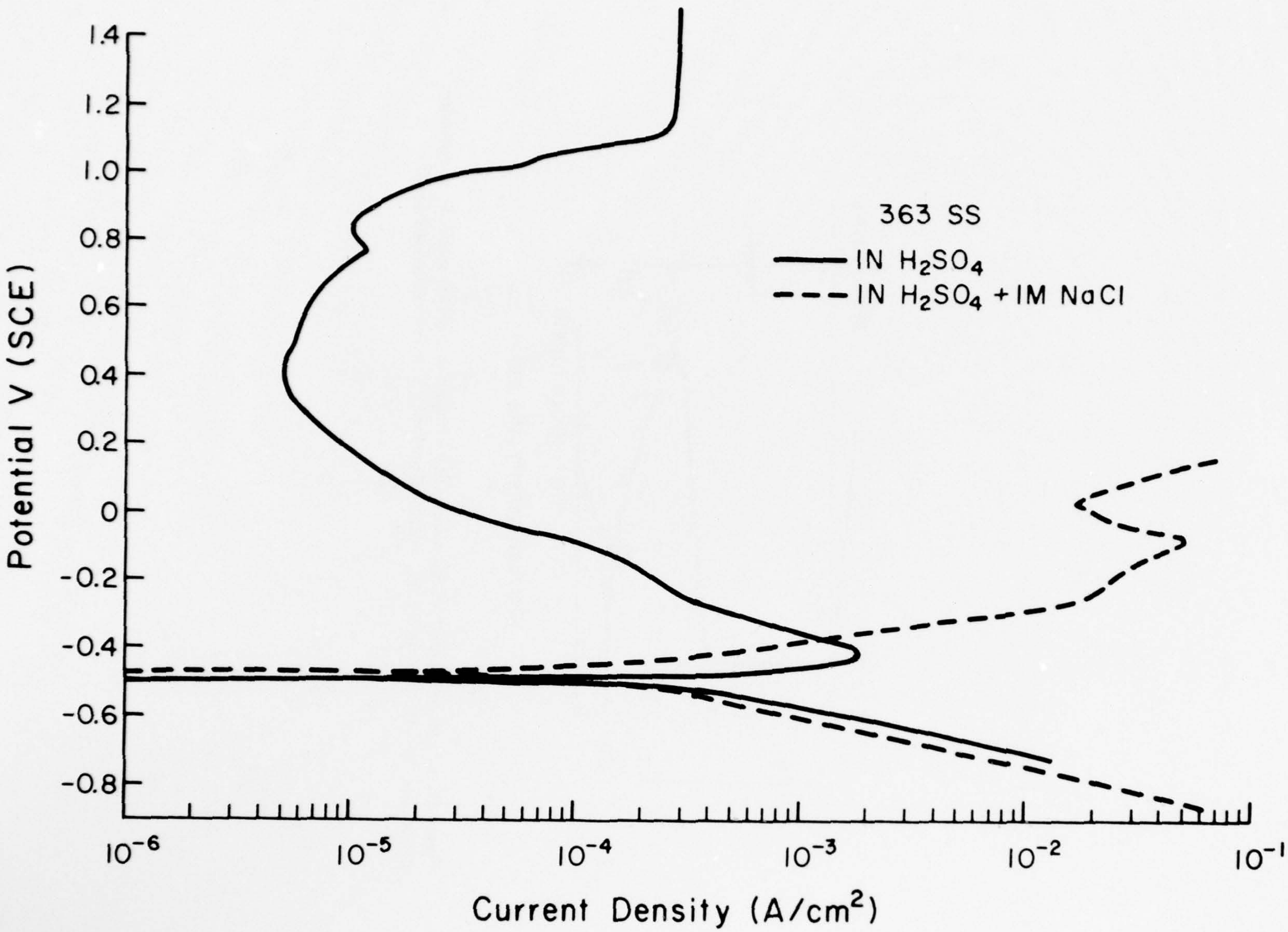


Figure 22. Potentiodynamic polarization curves for AM 363 stainless steel.

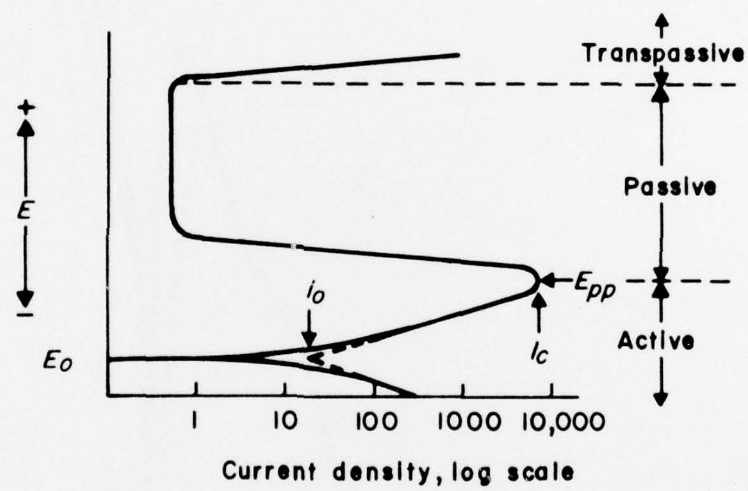


Figure 23. Schematic diagram of the polarization behavior of stainless steels. E_o = corrosion potential; i_o = corrosion current; E_{pp} = critical potential; I_c = critical current density.

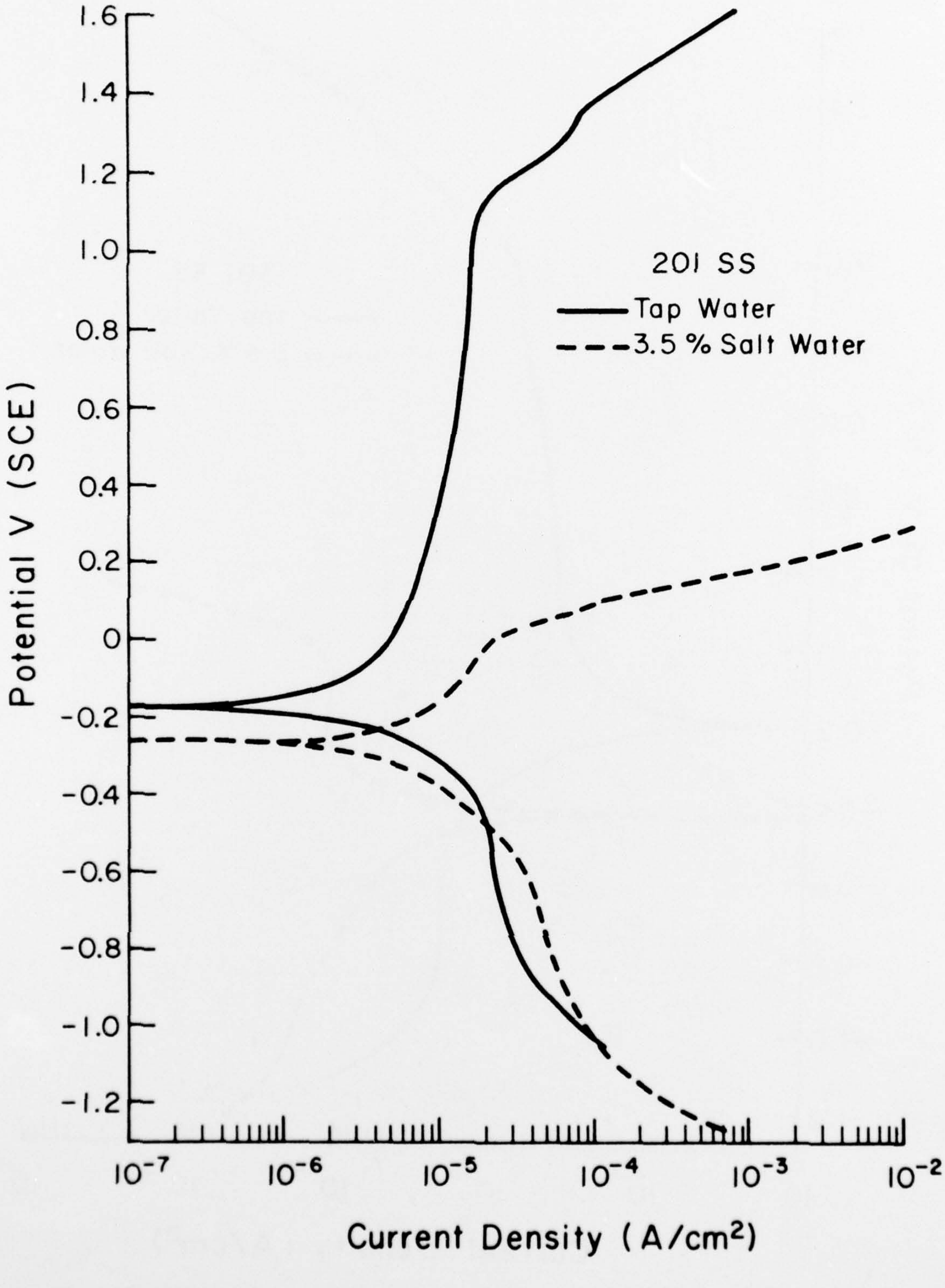


Figure 24. Potentiodynamic polarization curves for AISI 201 stainless steel in tap water and salt water.

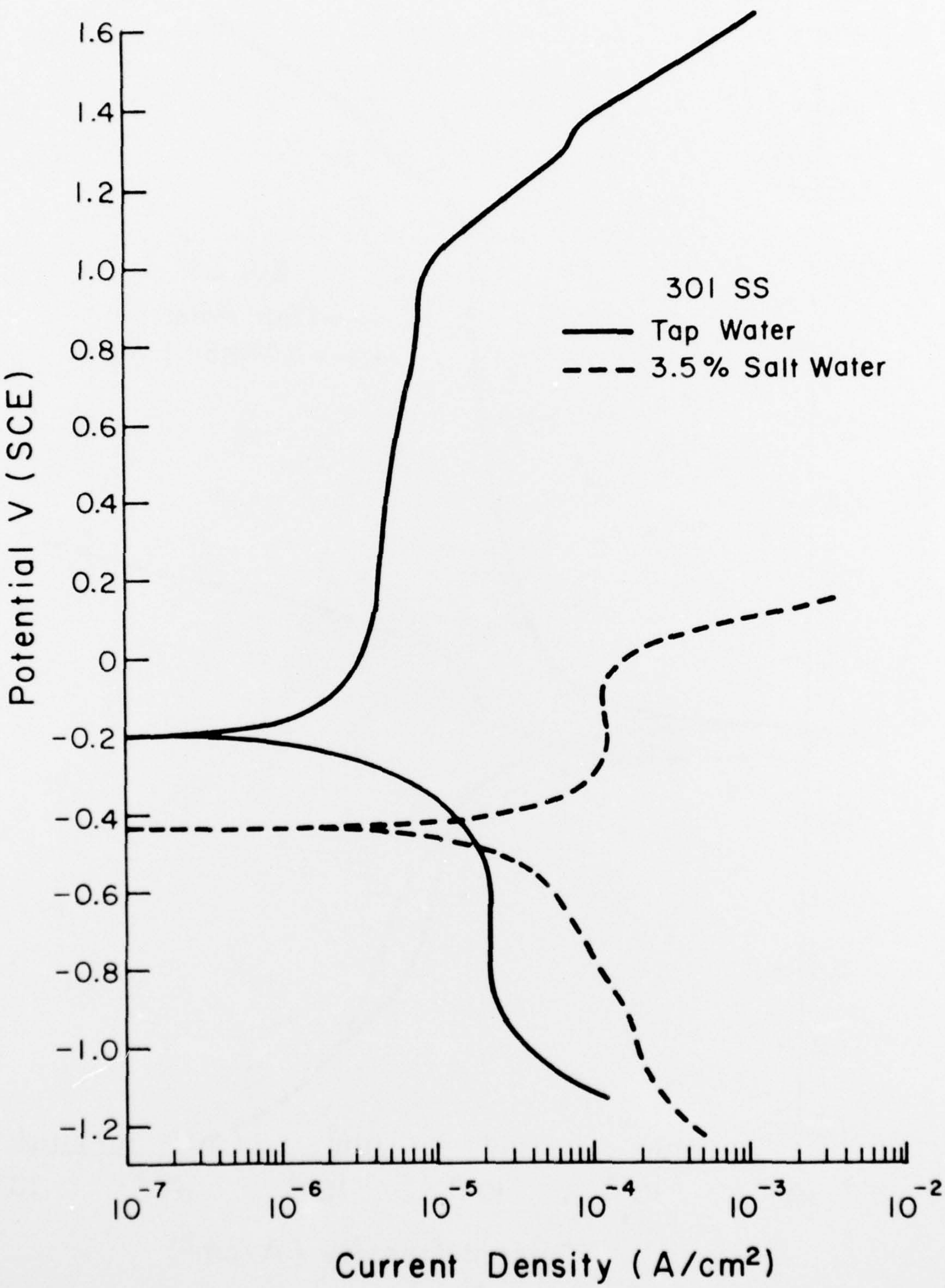


Figure 25. Potentiodynamic polarization curves for AISI 301 stainless steel in tap water and salt water.

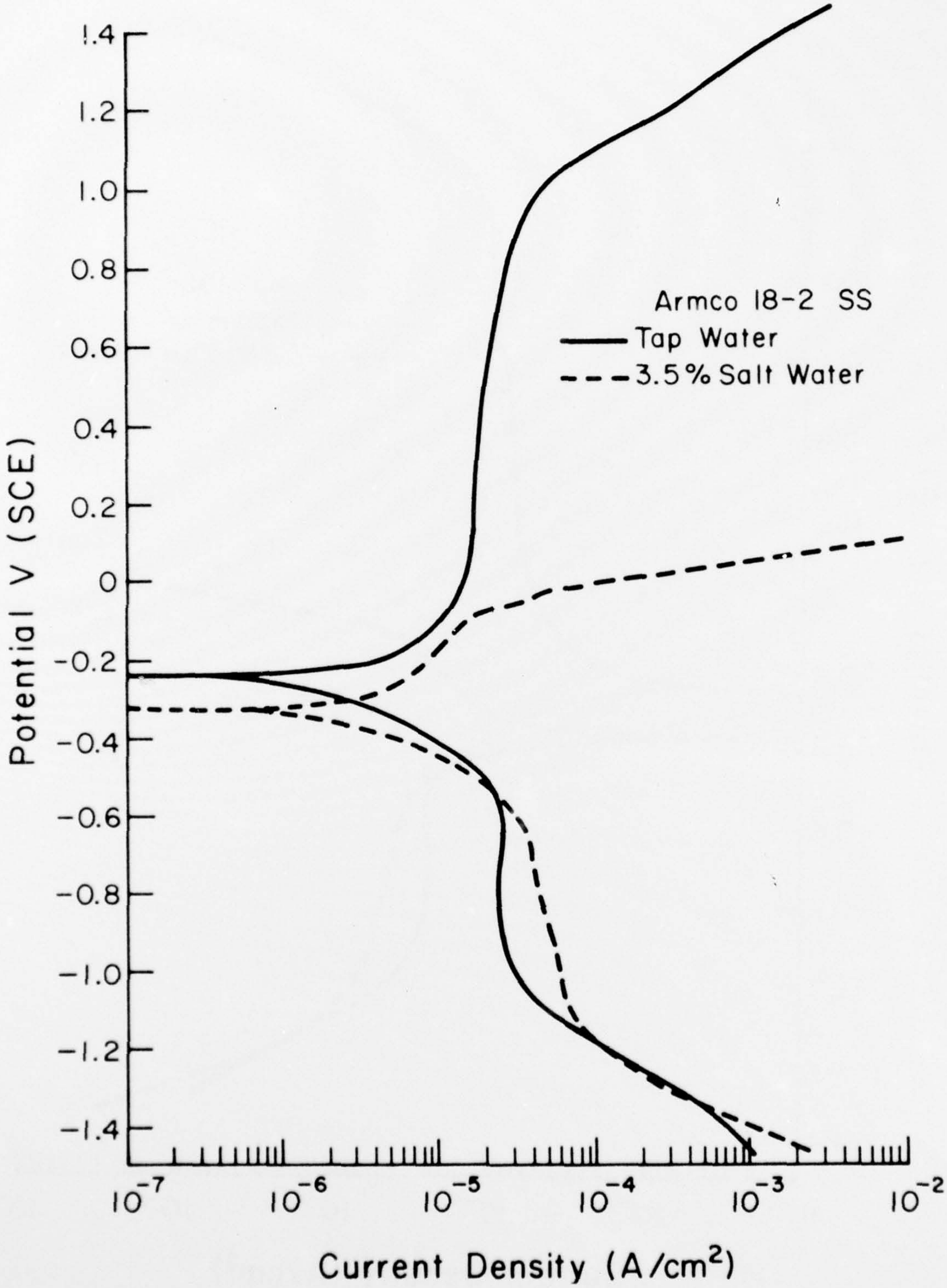


Figure 26. Potentiodynamic polarization curves for Armco 18-2 stainless steel in tap water and salt water.

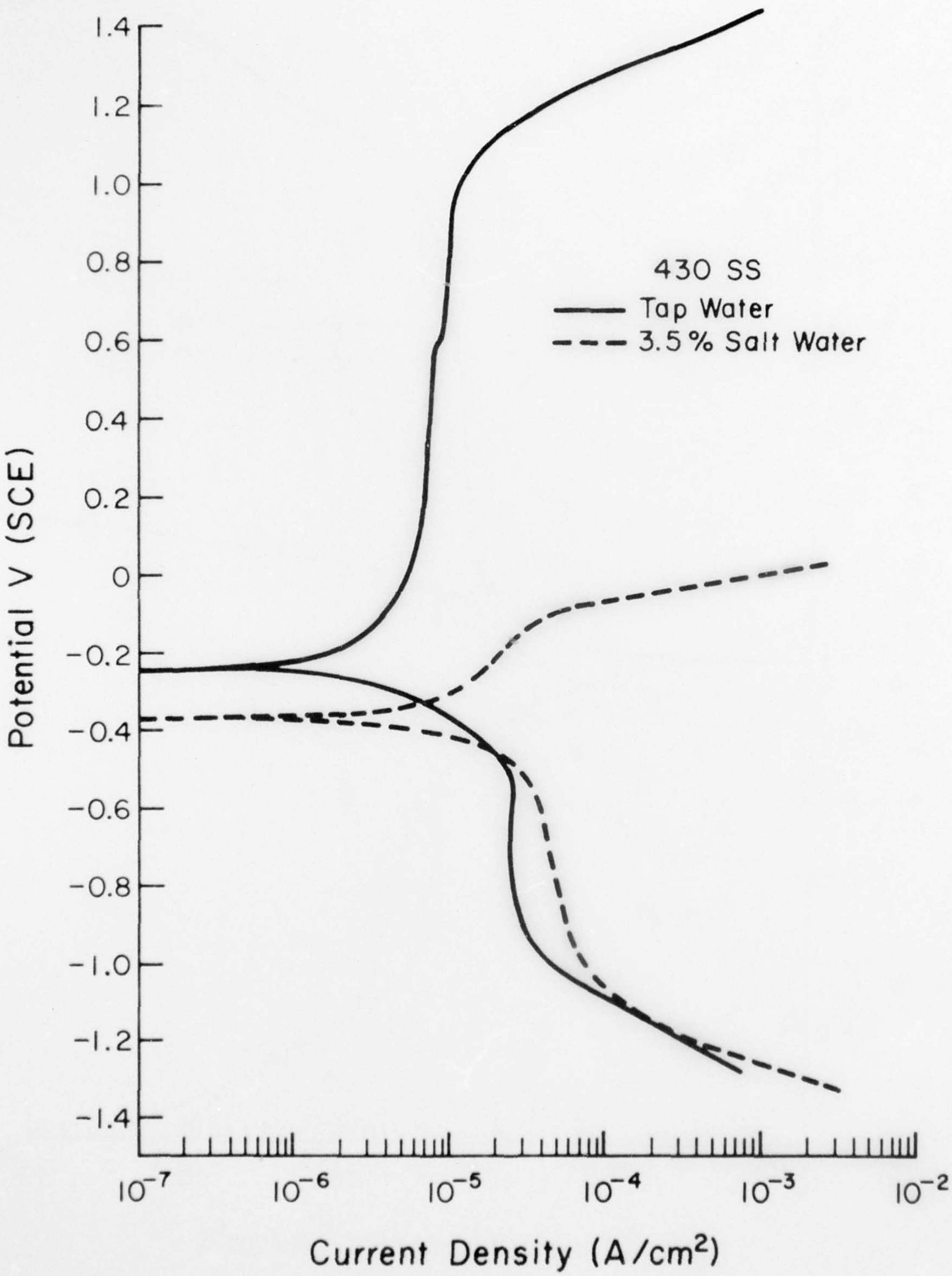


Figure 27. Potentiodynamic polarization curves for AISI 430 stainless steel in tap water and salt water.

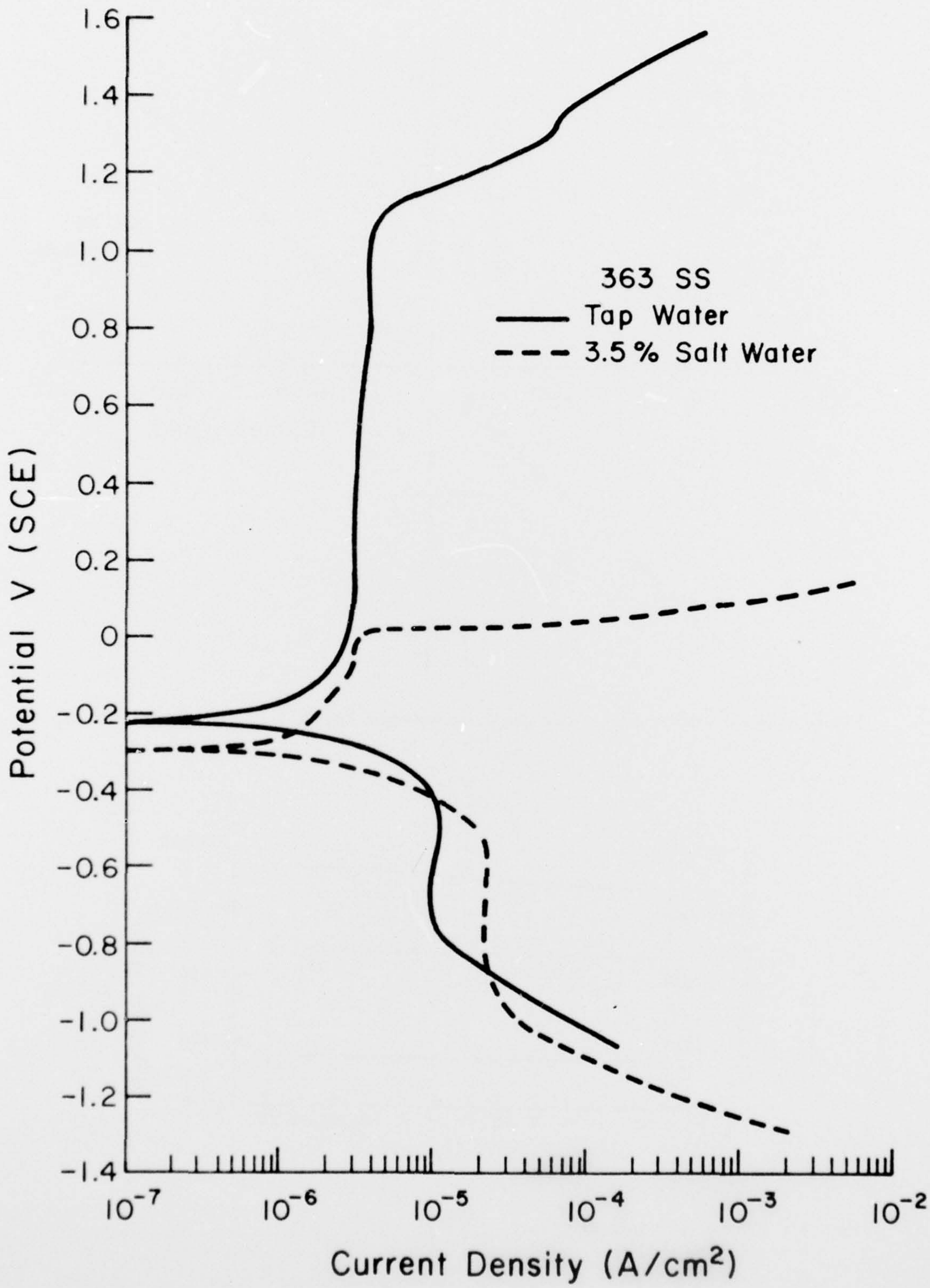


Figure 28. Potentiodynamic polarization curves for AM 363 stainless steel in tap water and salt water.

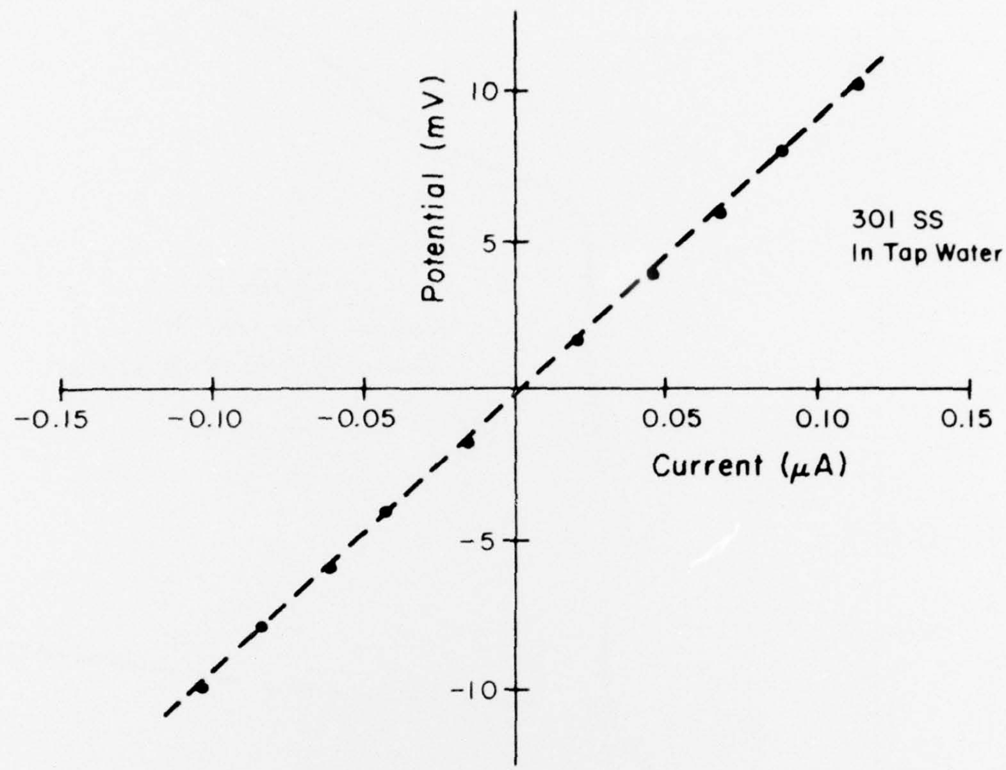
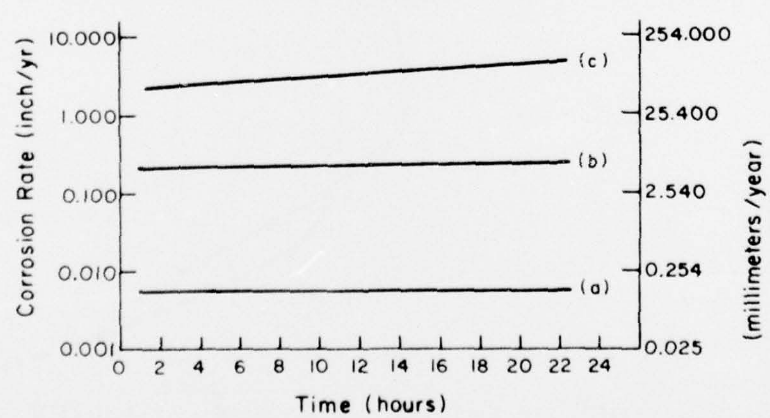


Figure 29. Results of the linear polarization measurements for AISI 301 stainless steel in tap water.



Key: a = free corrosion without contact
b = area ratio of 0.004
c = area ratio of 0.00006

Figure 30. Effect of anode-to-cathode ratio on corrosion rates of low-carbon steel coupled to copper in tap water. Note that the corrosion rate is in log scale.

APPENDIX:
PHYSICAL REQUIREMENTS FOR WIRE FABRIC MATERIALS*

Solicitation No. DACW66-70-R-0050

PART II - TECHNICAL PROVISIONS

SECTION 1 - GENERAL

1-01. General. The intent of these specifications is to secure noncorrosive fabric for the manufacture and assembly of articulated concrete mattress revetment. Articulated concrete mattress units or squares consist essentially of 20 concrete blocks in which is cast the fabric to form an articulated unit 25 feet by 4 feet. The fabric therefore is used as an assembly system for inter-connecting the 20 concrete blocks of a concrete mattress unit. To provide long life, the fabric must be manufactured from a material resistant to corrosion when subjected to air, or to water of the Mississippi River, whether alone or in contact with galvanized or ungalvanized steel, concrete, wood or other debris, or earth. To provide suitable handling and assembling characteristics, the fabric must be sufficiently stiff as to not be unduly deformed by normal handling and yet must be sufficiently flexible to permit the concrete mattress to conform to the irregularities of the river bed.

1-02. Type of Materials. (See paragraph 2b) The fabric shall be manufactured from material having corrosion resistant characteristics equal to or better than the AISI, Type 301 chrome-nickel steel, or of material with a non-corrosive metallic covering. Bi-metallic wire shall have a minimum covering of at least six thousandths (0.006) of an inch in thickness, and in addition shall have a sufficient thickness of covering to provide the equivalent protection afforded by a coating of commercially pure copper of six thousandths (0.006) of an inch properly applied to the steel core. The covering metal must be permanently and integrally attached to the core metal and must be uniform, dense, non-porous, and free from inclusions, laps, seams, splits, checks and slivers and nodules tending to separate or break away from the wire itself.

*From *Specifications for End Twist Wires (Wire Forms) and Straight Wires*, Solicitation No. DACW66-70-R-0050 (Corps of Engineers Memphis District, 1973).

SECTION 2 - FABRIC

2-01. Physical Requirements. The fabric shall meet the following requirements:

a. Size of Wires. Wire used in manufacturing the fabric shall have a nominal diameter of not less than 0.162 inch nor more than 0.225 inch. Prior to beginning of manufacture, the Contractor shall advise the Contracting Officer of the diameter of the wire he proposes to use. A variation of 2 percent plus or minus from the approved nominal diameter will be permissible.

b. Fabrication. The reinforcing fabric shall be manufactured in accordance with the details shown on the attached drawing, Serial No. 14107 File C1/31.1. The end loops shall be parallel to the plane of the fabric assembly within a tolerance of 10 degrees. When the end loop is formed by a mechanical tie, the end bracket wire shall be included in the tie. Joints in longitudinal wires of bi-metallic construction shall be made so that the core metal will be covered with a minimum thickness of ten-thousandths (0.010) of an inch of non-corrosive metal. No portion of the weld of a bi-metallic longitudinal wire shall be more than 5 inches from the nearest bracket wire. Samples of the proposed joint shall be submitted for approval before being used. The joint or splice in the wire forming the bracket wire shall be made within the middle third on the bracket. Brackets may be made from two pieces of wire instead of one, provided that not more than 2 percent of the total number of brackets supplied are made by this method. Bracket wires may be fastened to the longitudinal wire by mechanical or welded ties as shown on the drawing, except that welding of bi-metallic wire that destroys the non-corrosive qualities of the wire will not be permitted. Non-corrosive mechanical ties will not be required. The limits of error permissible in the completed fabric are as follows:

Bracket dimensions: 1/4 inch plus or minus the dimensions shown on the drawing.

Spacing of wires in fabric: 1/4 inch plus or minus the position shown on the drawing.

Overall length: 1/2 inch plus or minus the length shown on the drawing.

End loops: 1/8 inch plus or minus the specified inside diameter shown on the drawing.

c. Tensile Strength. (1) Wire used in manufacturing the fabric shall have a breaking strength of not less than 4,000 pounds in at least 75 percent and not less than 3,600 pounds in the remaining 25 percent of the specimens tested.

(2) Fabrication Joints. Any joint or splice in a longitudinal wire shall have a tensile strength at least equal to that specified for the wire. At least 75 percent of the joints or splices in wires used as bracket wires in the fabric shall have a breaking strength of not less than 3,200 pounds, and the remaining 25 percent of the joints or splices in the bracket wires shall have a breaking strength of not less than 2,900 pounds. The end loops in the longitudinal

wires of the fabric shall develop the same breaking strength specified for the wire. Joints fastening the bracket wires to the longitudinal wires in the fabric shall not reduce the specified breaking strength of the wires to less than 3,600 pounds and shall have a shearing resistance of not less than 100 pounds.

d. Bending. The wire from which the fabric is manufactured shall withstand a minimum of seven 90 degree bends without breaking and shall be capable of being wrapped around its own diameter 8 consecutive turns with a pitch substantially equal to the diameter of the wire without signs of imperfections.

e. Flexibility. The wire used in brackets shall have a permanent deformation angle between 22 and 35 degrees when subjected to the modified IZOD Impact Test prescribed in paragraph 2-02e.

2-02. Tests. The Contractor shall furnish a certified chemical analysis of each heat of the metal (core metal only for bi-metallic wire), from which wire for use in fabricating the fabric is drawn. In addition, and at the Contractor's expense, the finished wire shall be subjected to the following tests to determine that it meets the requirements of these specifications:

a. Tensile Strength. Tensile tests to determine the breaking strength of the fabric wire and various portions of the fabric shall be made as follows:

(1) Straight unjointed pieces of the wire,

(2) End loops in each end of the longitudinal wire in the fabric,

(3) Joints or splices in the bracket and longitudinal wire,

(4) Pieces of wire on which joints fastening bracket wires to longitudinal wires have been made,

(5) Shear tests to determine the strength of joints fastening bracket wires to longitudinal wires.

At least one tensile strength test of the wire shall be made of each coil of wire approximately 1,000 pounds. One square from each 1,000 squares of fabric manufactured shall be selected and a tensile strength test made of at least two end loops in the end of the longitudinal wires; four joints in bracket wires; one joint or splice in the longitudinal wires; and three pieces of longitudinal wires and three pieces of bracket wires on which joints fastening bracket wires to longitudinal wires have been made. From this same square of fabric, three shearing strength tests of the joints fastening bracket wires to longitudinal wires shall be made. Tests on end loops formed by a mechanical tie shall be made by holding the longitudinal wire and the two portions of the bent back bracket wire included in the tie in one jaw of the testing apparatus. The end loop shall be subjected to a pull applied on the end of the loop through a "U" shaped loop of wire having a nominal diameter of not less than 0.195 inch nor more than 0.225 inch or through any apparatus which will apply the required pull on the end of the loop and is so designed that its shape at the point of contact with the loop simulates that of a wire of not less than 0.195 inch nor more than 0.225 inch diameter. Tests on end loops formed by a welded tie shall be made by holding the

longitudinal wire outside the limit of the weld in one jaw of the testing apparatus and the remaining portion of the test performed as described above. Should any specimen fail to meet the required tests, such additional tests as necessary to detect any other unsatisfactory wire or fabric shall be made, and all wire or fabric failing to meet the requirements set forth herein shall be rejected.

b. Bending. The following tests shall be made from each coil of approximately 1,000 pounds of the wire from which the fabric is to be manufactured.

(1) A length of wire shall be held between jaws having edges rounded on a 3/8" radius. The free end of the wire shall be bent over the rounded edges back and forth through an angle of 180 degrees between limiting positions on opposite sides of, and at right angles to, the original straight wire. Specimens shall be straight and shall extend approximately 10 inches from the support. Bends shall be made at as nearly a uniform speed as possible, not exceeding 50 bends per minute and in no case shall the speed be so great as to cause undue heating of the wire. Each 90° movement in either direction shall be counted as one bend. The number of bends shall be counted until the specimen is severed. When failure occurs, 90 percent of the specimens shall have withstood at least 7 bends. Bi-metallic wire, when broken by repeated bending, shall show no separation of the covering from the core metal.

(2) A length of wire shall be wrapped around its own diameter 8 consecutive turns with a pitch substantially equal to the diameter of the wire without signs of imperfections.

Failure of these tests will result in rejection of the wire represented by the sample.

c. Quality of Coating of Bi-Metallic Wire. The following test of the quality of coating of bi-metallic wire shall be made on one specimen from each 200 pounds of wire:

(1) Lengths of wire after having been wrapped as prescribed in paragraph 2-02b(2) shall be subjected to a ferroxyl test to be made as follows:

First: Samples shall be immersed in a 15% solution by weight of hydrochloric acid for approximately one hour or longer or in a 25% solution by weight of hydrochloric acid for approximately 15 minutes to remove ferrous contamination of the surface. If surface contamination is still present, the wire may be immersed for 10 seconds in a 50% solution of nitric acid.

Second: Sample shall then be immersed for one minute in a solution of:

10 grams of Potassium Ferricyanide
1000 cc Distilled Water
20 grams of Concentrated Sulphuric Acid

The appearance of blue spots or lines on the samples indicates porosity, flaking, cracks, or interstices showing the solution is in contact with the steel core. If this occurs, four additional specimens shall be prepared and subjected to the ferroxyl test. Failure of any of these retest specimens will result in rejection of material covered by the tests.

(2) The wrapped specimen shall be closely examined to determine any imperfections in the wire. If any inclusions, slivers, cracks or nodules are found in the surface metal the specimen will be subjected to first, the ferroxyl test as described in paragraph 2-02c(1); then to a microscopic examination to determine the thickness of surface metal at the imperfection. Surface metal, not including the imperfection, should be of a minimum thickness as required in paragraph 1-02. If the specimen fails either of the tests, four additional specimens will be examined. Failure of any of the additional specimens will result in rejection of the material covered by the test.

d. Thickness of Coating. Thickness of coating of bi-metallic wire shall be determined by one of the following methods on each 200 pounds of wire from which fabric is to be manufactured:

(1) After thoroughly cleaning the test specimens with carbon tetrachloride, or other grease remover, they shall be immersed in nitric acid for approximately 30 seconds or longer, and then removed and quickly immersed in water to stop the action of the acid. This cycle shall be repeated until the diameter of the wire shall have been reduced at least 2 times the guaranteed minimum thickness of the metallic covering for a length of not less than 1/2 inch. If pitting should occur during this treatment, the specimen shall be burnished with steel wool. At that part of the wire which shows a reduction in diameter of 2 times the guaranteed minimum thickness of the copper covering when measured with a micrometer, the wire shall remain covered with the coating. If any core metal should be visible at any point where the specimen measures two times the guaranteed minimum thickness of the covering less than the original diameter, a microscopic measurement of a duplicate specimen shall be made. Should the microscopic measurement show the covering to be less than the guaranteed minimum thickness of the covering, the coil of wire which the specimen represents shall be rejected.

(2) Removing sufficient coating and accurately gaging with suitably accurate apparatus.

(3) Cutting off the wire, grinding smooth, and etching its exposed cross section, and gaging by suitably accurate apparatus.

(4) Using electrical indicating instruments of suitable accuracy.

e. Flexibility. (1) Materials for bracket wires will be further tested for flexibility. Preliminary investigations indicate that a modification of the IZOD Impact Test (ASTM, E23-47T, Impact Testing of Metallic Materials) will establish the suitability of a type of material, strength and diameter, as affecting flexibility.

(2) The test shall be made with a pendulum type impact machine in the manner prescribed in ASTM, E23-47T for the Cantilever Beam (IZOD type)

tests except that the blow delivered shall be equal to that delivered by the Tinius Olsen apparatus (120 ft. lbs. IZOD capacity) when the pendulum travels 11 inches measured on the chord (the Tinius Olsen machine has a secondary safety stop at this position on the pendulum arm). The mechanism for releasing the pendulum from its initial position shall be such that it operates freely and permits a free start without initial impulse, retardation or side sway.

(3) The specimen shall be a straight wire of the material, strength and diameter proposed. The specimen shall not be notched. The length of the specimen, extending out of the gripping device shall be 28 mm (1.102") and the striking mechanism shall deliver the blow 22 mm (0.866") from the edge of the gripping device.

(4) The striking mechanism will be allowed to deliver only one blow. If the pendulum passes completely over the specimen, the specimen shall be rejected. The specimen shall be removed from the vise after one blow is delivered and the resultant deformation measured. Only materials resulting in a permanent deformation angle between 22 and 35 degrees will be considered satisfactory.

One flexibility test shall be made from each coil of approximately 1,000 pounds of wire.

f. Frequency of Tests. After demonstration of uniformity of quality of production, the frequency of the tests prescribed in paragraphs 2-02a, b, c, d and e above, may be reduced to one test each for each 4,000 pounds of wire from which fabric is to be manufactured and one test for each 4,000 squares of fabric manufactured.

2-03. Packaging. The fabric shall be packed in bundles of 300 squares of fabric laid flat on a stout cradle. The fabric shall be securely fastened or tied on the cradle. The cradles shall be so designed and constructed that handling loops attached to a lifting frame may be swiftly and easily applied to lift the whole cradle and bundle without damage. All fastenings, ties, handling slings, etc., shall be applied in such a manner that the fabric will not be damaged or bent in handling.

All cost of packing and preparing for shipment shall be included in the price bid on the fabric.

MSM

CERL DISTRIBUTION

Director of Facilities Engineering
APO NY 09827

DARCOM STIT-EUR
APO New York 09710

West Point, NY 10996
ATTN: Dept of Mechanics
ATTN: Library

Chief of Engineers
ATTN: DAEN-ASI-L (2)
ATTN: DAEN-FEU
ATTN: DAEN-FEZ-A
ATTN: DAEN-MCZ-S
ATTN: DAEN-RDL
ATTN: DAEN-PMS (6)
for forwarding to
National Defense Headquarters
Director General of Construction
Ottawa, Ontario K1A0K2
Canada

Canadian Forces Liaison Officer (4)
U.S. Army Mobility Equipment
Research and Development Command
Ft Belvoir, VA 22060

Airports and Const. Services Dir.
Technical Information Reference
Centre
KAOL, Transport Canada Building
Place de Ville, Ottawa, Ontario
Canada, K1A0N8

Ft Belvoir, VA 22060
ATTN: Kingman Bldg, Library

Ft Monroe, VA 23651
ATTN: ATEN

Ft McPherson, GA 30330
ATTN: AFEN-FED

USA-WES
ATTN: Concrete Laboratory
ATTN: Library

6th USA
ATTN: AFKC-LG-E

US Army Science & Technology Center
- Far East Office

US Army Engineer District
Buffalo
ATTN: Library
Pittsburgh
ATTN: Library
Philadelphia
ATTN: Library
ATTN: Chief, NAPEN-D
Baltimore
ATTN: Chief, Engr Div
Norfolk
ATTN: Chief, NAOEN-D
Wilmington
ATTN: Chief, SAWEN-D
Charleston
ATTN: Chief, Engr Div
Savannah
ATTN: Library
ATTN: Chief, SASAS-L
Jacksonville
ATTN: Library
ATTN: Const. Div
Mobile
ATTN: Chief, SAMEN-C
ATTN: Chief, SAMEN-D
Nashville
ATTN: Library
Memphis
ATTN: Chief, LMMED-DM
Vicksburg
ATTN: Chief, Engr Div
Louisville
ATTN: Chief, Engr Div
St Paul
ATTN: Chief, ED-D
St Louis
ATTN: Library
Kansas City
ATTN: Library (2)
Omaha
ATTN: Chief, Engr Div

US Army Engineer District
New Orleans
ATTN: Library
ATTN: Chief, LMNED-DG
Little Rock
ATTN: Chief, Engr Div
Tulsa
ATTN: Library
Albuquerque
ATTN: Library
San Francisco
ATTN: Chief, Engr Div
Sacramento
ATTN: Chief, SPKED-D
Japan
ATTN: Library
Portland
ATTN: Chief, DB-6
Seattle
ATTN: Chief, NPSCO
Walla Walla
ATTN: Library
ATTN: Chief, Engr Div
Alaska
ATTN: Library
ATTN: NPADE-R

US Army Engineer Division
Europe
ATTN: Technical Library
New England
ATTN: Library
ATTN: Chief, NEDED-T
North Atlantic
ATTN: Chief, NADEN-T
South Atlantic
ATTN: Chief, SADEN-TS
ATTN: Library
Huntsville
ATTN: Library (2)
ATTN: Chief, HNDED-CS
ATTN: Chief, HNDED-SR
Lower Mississippi Valley
ATTN: Library
ATTN: LMVED-C (30)
Ohio River
ATTN: Library
ATTN: Chief, Engr Div
North Central
ATTN: Library
Missouri River
ATTN: Library (2)
Southwestern
ATTN: Library
ATTN: Chief, SWDED-TM
Pacific Ocean
ATTN: Chief, Engr Div
North Pacific
ATTN: Chief, Engr Div

Facilities Engineers
Ft Campbell, KY 42223
USAECOM
Ft Monmouth, NY 07703
DFAE, USAIC
Ft Benning, GA 31905
TRADOC
Ft Knox, KY 40121
Ft Sill, OK 73503
Ft Bliss, TX 79916
HQ, 1st Inf Div & Ft Riley
HQ, 5th Inf Div & Ft Polk
HQ, 7th Inf Div & Ft Ord

AF Civil Engr Center/XRL
Tyndall AFB, FL 32401

Naval Air Systems Command
ATTN: Library
WASH DC 20360

Naval Facilities Engr Command
ATTN: Code 04
Alexandria, VA 22332

Port Hueneme, CA 93043
ATTN: Library (Code L08A)

Washington, DC
ATTN: Transportation Research Board
ATTN: Library of Congress (2)
ATTN: Dept of Transporation Library

Defense Documentation Center (12)

Engineering Societies Library
New York, NY 10017

US Army/FESA
Bldg 358
Ft Belvoir, VA 22060